Lardeau River Fish Habitat Assessments (2002) and Preliminary Gerrard Rainbow Trout Production Capability Modeling

P. Slaney[1] and H. Andrusak[2]

Plate 1. A natural lateral logjam that has resulted in a scour pool/run in Reach 4 of the Lardeau River, which provides prime rainbow parr habitat, as well as bull trout, mountain whitefish, and kokanee habitat. Note the keystone species, kokanee, in the foreground which supply significant nutrients and energy (eggs/fry) for production of Gerrard rainbow trout and other species (September 27, 2002).

SUMMARY

A habitat assessment of the Lardeau River was conducted in September 2002. Habitat conditions in all reaches of the Lardeau River are highly driven by the existing large wood within the river channel the wood's primary re-supply is from the riparian areas of the floodplain. Large wood is abundant in all reaches, with extensive log jam development, and was particularly plentiful in the mid-river and lower-river reaches. The total channel LWD was rated as "good" based on the assessment procedure using total channel wood. Riparian conditions are highly dominated by young forest and secondarily pole sapling, the latter largely as a succession stage in meander bends. This condition is expressed in LWD in the river, which is shifting towards smaller pieces (on average 52 % < 30 cm basal diameter). This trend is predicted to increase in frequency in the future. As existing larger diameter wood gradually decays and is transported over time, re-supply will be mainly from small diameter wood <30 cm. Fortunately, in the interim period, the relatively high incidence of Western Red Cedar in the channel, which decays more slowly, is delaying a reduction in crucial habitat features of Gerrard rainbow trout.

Several pool and cover characteristics rated more within the "fair" range than "good" range, and large wood played a dominant role over all other cover types. Secondary or pocket pools, rather than frequency of primary pools, was the reason for only the "fair" pool rating and a reflection of the dominance of young forest within the riparian zone. Side-channels were well developed in all reaches and likely provide considerably more fry habitat than parr habitat, whereas parr habitat was much more abundant than fry habitat in the mainstem. In the Duncan River, diverse habitat units exist with significant side-channel development in some reaches, but pools were almost non-existent. The river flowed at high velocities and depths well into the vegetated edge of the riparian zone in mid-summer to fall. Useable underyearling habitat appeared to be sparse, although this was not quantified by hydraulic unit as in the Lardeau River.

A parr model was developed using steelhead biostandards to estimate total Gerrard rainbow trout parr yield from the Lardeau River and its side-channels. The model predicted a that the river could support 47,042 parr and 49,817 including the lower Duncan River. This is about 30 % less than that predicted by Irvine (1978). However, it was evident that useable fry habitat was probably underestimated and needs refinement by depth and velocity measurements to obtain weighted useable areas. The estimate of useable area and model fish densities need further refinement because the predicted density per area of useable habitat was about twice that expected for an Interior stream of moderately high productivity.

A series of recommendations are made on habitat restoration initiatives as well as recommendations on further survey work and ways to improve upon the model.

Lardeau River Fish Habitat Assessments (2002) and Preliminary Gerrard Rainbow Trout Production Capability Modeling

P. Slaney[1] and H. Andrusak[2]

INTRODUCTION

Kootenay Lake arguably supports the most intensive inland fishery in the province with the primary focus of most anglers being the Gerrard strain of rainbow trout. These trout are the largest sized wild trout known to exist in North America with some growing as large as 15 kg. This unique race of wild rainbow trout is totally dependent upon natural production from the Lardeau River. This river is the largest free flowing system remaining on Kootenay Lake that has not been impacted by hydroelectric development. The Kootenay River downstream of the West Arm of Kootenay Lake was impacted by the Corra Linn Dam completed in 1931 (Northcote 1973), the Goat River built in the 1930s totally blocked fish migrations as did the Duncan River system altered by construction of the Duncan Dam in 1967-1968. The Kootenay River entering at the south end of the lake was radically altered in the mid 1970s by development of the Libby Dam located in Montana (Northcote 1973; Daley et al. (1981).

The Lardeau River forms at the outlet of Trout Lake located 50 km north of Meadow Creek, British Columbia. It flows approximately 40 km in a southeastern direction where it joins the Duncan River about 10 km before emptying into Kootenay Lake. It is the most important production river for Kootenay Lake fish populations providing spawning and rearing habitat not only for Gerrard rainbow trout but also for kokanee, whitefish, dace, burbot, sculpins and bull trout. Even though the Lardeau River remains a free flowing river, it has been impacted by linear development (highway, logging roads) and a century of forest harvesting in the riparian and main valley areas.

There have been a series of impacts to Kootenay Lake as a result of upstream impoundments and operation of a fertilizer plant upstream of the lake. Northcote (1973) described the cultural eutrophication of the lake in the 1960s and 1970s due to phosphorous introduction from a fertilizer plant into a tributary of the Kootenay River some 400 km upstream from the lake. Daley et al. (1981) described in considerable detail the reversal of eutrophication during the late 1970s and early 1980s and attributed the change to cessation of the phosphorous discharge and nutrient retention due to formation of reservoirs on the two major inflow rivers (Kootenay and Duncan). Daley et al. (1981) correctly predicted that the lake would revert to an oligotrophic state and recent limnological data confirms the lake is again oligotrophic (Ashley et al. 1997; Wright et al. 2002).

---

[1] PSlaney Aquatic Science Ltd., 214 Nelson Street, Coquitlam, BC V3K 4M4
[2] Redfish Consulting Ltd., 5244 Highway 3A, Nelson, BC V1L 6N6

Within the Kootenay Lake basin the Lardeau River supports the largest natural spawning population of kokanee. In some years, over one million kokanee spawn throughout the river. Several fish species inhabiting Kootenay Lake are highly dependent on kokanee as forage including bull trout, burbot, pike minnow, and sturgeon. Gerrard rainbow trout rely almost exclusively on kokanee for food once they enter the lake (Andrusak and Parkinson 1984). Not surprisingly, there was great concern for the future of these trout when Kootenay Lake kokanee underwent a dramatic decline in the late 1980s. In response to the decline, fisheries managers undertook an ambitious experiment to fertilize a small portion of the North Arm. This was an attempt to restore the nutrient balance that had been changed as a result of two upstream dams and closure of the fertilizer plant (Larkin 1998; Ashley et al. 1998). Fertilization began in 1992 and Ashley et al. (*in* Murphy and Munawar 1999) described the experimental design and initial results. In short, the North Arm kokanee population has responded to lake fertilization and recovered to near historical numbers. With the recovery of kokanee in Kootenay Lake in the mid 1990s the Gerrard rainbow trout appear to have responded as reflected in increased escapements and catch in the late 1990s (Redfish Consulting Ltd. 2002).

Sport fishing on Kootenay Lake is a major attraction for anglers from many areas of the province as well as nearby non-residents from Alberta, Idaho, Montana, and Washington. The diversity of fisheries available has been the dominant attraction for the entire region in terms of quality fishing and at one time Kootenay Lake supported the largest inland fishery in British Columbia (Andrusak and Brown 1987). The lake offers a variety of fisheries for rainbow trout, bull trout, whitefish, and kokanee. During the peak of fishing in the 1970s angler effort exceeded 50,000 angler days but today it has lowered to about 25,000. The majority of fishing effort is directed at the highly sought trophy-sized Gerrard rainbow trout. These fish are often caught in the size range of 10-13 kg making them the largest trout caught anywhere in North America. Several multi million dollar sport fish based resorts have been developed on the lake during the last two decades that are highly dependent on fishing for Gerrard rainbow trout. The popularity of Kootenay Lake fishing among both resident and non-resident anglers has resulted in a very intensive fishery that is accompanied by high public expectations. Fishing by both resident and non-resident anglers for Gerrard rainbow trout occurs at such high levels that the annual exploitation rate exceeds the sustainable level. As such the population could be easily over-fished were it not for a catch and release rate that is over 60% (Redfish Consulting Ltd. 2002).

Over the last 50 years considerable research has been undertaken to understand the biology of this unique race of trout. A great deal is known of their early life history. For example, these fish spawn in May and their progeny emerge in early July (Irvine 1978). Most of the young fish move down the Lardeau River a few weeks after emerging from the spawning grounds. As they move downstream the fry saturate available rearing habitat along the river margins and side channels with some fry entering the lake presumably because all available rearing habitat is utilized. Okanagan Lake rainbow trout spawning in Mission Creek have a similar life history strategy with only fish that rear in the stream for 1-2 years contributing to the adult population (Sebastian 1979). Based on the work of Sebastian (1979) and Burrows (1993) it is also believed that most surplus fry entering Kootenay Lake do not survive to adult size fish. A significant and critical feature of these trout is that the Lardeau River is the only system within the entire Kootenay Lake basin where they are known to spawn and rear. Based on this knowledge and in consideration of their value there has been some recent effort made to identify rainbow trout habitat restoration opportunities (Redfish Consulting Ltd. 2001) including one attempt at constructing a side channel to encourage use by over wintering parr (Redfish Consulting Ltd. 2001). There is evidence that side-channel habitat has been historically lost to railway and road construction along the Lardeau-Duncan system.

Perhaps the most compelling reason to consider restoring Gerrard rainbow trout habitat in the Lardeau River stems from the fact that a similar population of trout was completely eliminated as a result of construction of the Duncan Dam. Trout of equal size but probably fewer in number used to spawn at the outlet of Duncan Lake before it was flooded to establish Duncan Reservoir behind Duncan Dam. The author witnessed these large trout attempting to ascend the Duncan Dam tailrace for several years in the late 1960s and early 1970s. There is no evidence these fish persist today and consequently, the remaining Gerrard population is even more valuable than ever.

With the intense interest and extensive fishing pressure directed at this stock as well as past habitat impacts there is a growing need to have better information on the riverine population dynamics. A more comprehensive assessment of Gerrard rainbow trout fry and parr densities is required to gain an understanding of (a) the initial impact of Mobbs Creek debris torrents, and, (b) what the river carrying capacity is for these trout. Initial results of the 2002 fry assessment work by Redfish Consulting Ltd. (2002) indicated that fry densities were low compared to previous Lardeau River assessments and those of similar sized rivers in southern BC. In order to answer the question of carrying capacity there needs to be an assessment not only of fry and parr densities but also how much useable habitat there is within the river. To date there has been little attention directed at assessing Lardeau River habitat characteristics and therefore, this is the primary objective of this study.

Specific study objectives include:

1. assessment of the possible extent of impaired habitat affected by past logging of the floodplain and early railway development;
2. preliminary modeling of rainbow trout parr production capability; and
3. identification of potential habitat restoration opportunities.

BACKGROUND

There has been a century of mining and logging in the Lardeau valley and these resource activities were the primary reason why the CPR built a railway into the valley in 1902 (Irvine 1978). Northcote (1973) provides a good outline of the development of mining on Kootenay Lake and several popularized books provide excellent summaries of the colorful but brief history of mining exploits in the Kootenay Lake and Lardeau Valley.

The CPR railroad grade was started at the townsite of Lardeau in 1898 and reached Gerrard in 1902, and thereafter, a saw mill at Trout Lake City was moved down the lake to Gerrard. Logging activities originated in the early 1900s in the Lardeau Valley (Alexander 1998). Those trees nearest to the riverbank were high-graded first, and were typically cut during the winter by loggers who lived in local camps. They were then decked on the riverbanks ready for a log drive when water was high in the spring. Between 1900 and 1912 several million board feet of logs were cut in the lower Lardeau-Duncan River area, and driven to Kootenay Lake (Alexander 1998). A sawmill was subsequently built at Cooper Creek and logs were pulled from the river there for milling of lumber, followed by construction of a mill at Howser on Duncan Lake. By 1927 and into the mid-1930s, cottonwood as well as red cedar logging was also underway, which were also driven down the river, and crews worked the lower river jam and bars to free logs from hang-ups. By 1942, the CPR rails were lifted and the rail-bed was converted to a road and named Highway 31 north. By the1950s, logging was moving up the side valleys via roads including Meadow Creek and further up the Lardeau River. Evidence of old mines and old growth logging is apparent throughout the valley bottom, but while no mining activity exists today, there is still a considerable amount of logging on the hill slopes.

With the CPR railway in place between Lardeau and Gerrard near the turn of the century, it soon became apparent that some very large trout spawned at Gerrard located at the outlet of Trout Lake. Irvine (1978b) provides an excellent summary of the early fisheries work by the Federal Department of Fisheries including a description of seining for spawners and the extent of egg collections over a 50 year period. A hatchery was operated at Gerrard by the federal government starting in 1912 and later operated by the provincial government until the early 1950s. Due to the large size of these trout there was worldwide demand for their eggs. Egg collections continue periodically even today for sustaining a brood collection at the Wardner Hatchery, but the number of eggs collected are now less than 100,000 (annual) compared to a range of 0.2-1.4 million prior to the 1950s (Irvine 1978b).

By the 1950s egg collections from Gerrard rainbow trout had become a highly contentious issue because the local public resented eggs being shipped out of the area and because of the common practice of slitting the females to retrieve their eggs. A dramatic decline in escapements was evident by 1957 when only 54 fish were counted. In the minds of the public, the decline was due to the egg collections and strong protests led to cancellation of the practice and initiation of annual visual counts of spawner numbers (H. Sparrow, retired fisheries biologist, Victoria BC, pers. comm.). Annual counts of Gerrard spawners now span well over fifty years and provide an index of abundance for this population.

The Lardeau Valley is in the interior cedar hemlock biogeoclimatic zone. Forests in the watershed are dominated by cedar and hemlock with cottonwoods intermixed in the riparian zone. Higher elevations are represented by a mix of hemlock, spruce and minor amounts of fir and larch. Much of the logging that occurred in the riparian zone of the middle to upper took place in the 1960s and 1970s (G. Fitchett, logging contractor, Nelson BC, pers. comm.). During this era logging to the rivers edge on private and public lands was a common practice and most of these sites only now are starting to regenerate and become fully stocked with second growth forests. With the creation of the Goat Range Provincial Park in the late 1990s that includes more than half the valley bottom there is considerably more protection of the riparian zone although some private lands still can be logged to the rivers edge.

There have been long-term changes to the riparian areas of the Lardeau and Duncan rivers as a result of past logging of the floodplain. Today it is recognized that there is continuous recruitment of large wood to river channels and that the supply is greatly affected by logging to the riverbanks. Past LWD gradually is lost at 5-10% per decade and must be replaced by second growth wood (Koski 1992). During this process, which may takes 1-2 centuries, major changes in river geomorphology and fish habitat can occur (Slaney and Martin 1997). (A recent symposium held in Corvallis, Oregon, in 2000 reviewed 18 models of large wood cycles and dynamics in streams and rivers).

In the spring 2000, the Gerrard spawning grounds were impacted by a natural debris torrent that caused heavy sedimentation of the spawning gravel. There was a great deal of concern that much of the 2000 fry production had been lost. However, investigation of the river during late summer 2000 by Andrusak and Baxter (2000) revealed that an abundance of fry was evident along the periphery of the river. In 2001, and again in 2002, instability in Mobbs Creek watershed resulted in similar debris torrents when the rainbow trout were spawning at Gerrard. The 2002 event was particularly serious as the spawning fish were temporarily forced off the spawning grounds and remedial action (excavation of the Mobbs Creek fan to reduce the flooding impact) necessitated impairment of some redds. An assessment of fry densities in late summer 2002 by Redfish Consulting Ltd. (2002) indicates low numbers probably due to the impact on the spawning grounds. Assessment of the Mobbs Creek watershed suggests that natural slides may continue to cause problems in future. These flood events serve as a reminder of how vulnerable these trout are and reinforces the need to develop a long-term strategy to protect this valuable trout population.

The repeated debris torrents that have had some probable, unmeasured impact on the Gerrard spawning grounds has served to focus attention on the question of just how sustainable (assumed) is the Lardeau River habitat of Gerrard rainbow trout. Are there any and strategies that can be developed to mitigate for probable repeated debris torrent events an losses of riparian forests along the river? Certainly the immediate remedial work done at the Mobbs Creek confluence in 2002 was required but is this work by itself sufficient to protect this stock?

Increasing the amount of available rearing habitat for these trout is one strategy worthy of consideration, especially if there are opportunities for off-channel developments that would be a buffer against main river flood events. There is a good case to be made that this can be best accomplished by re-opening some side channels that have been cut off for years as a result of old railway grade construction, highway relocations and old logging road construction. No attempt has been made to quantify the extent of habitat loss although travelling along Highway 31 that parallels the Lardeau River provides several examples of inactive side channels cut off either originally by the railway or more recently by the highway. Some of these side channels are 0.3-0.7 km in length. Extensive clear-cut logging on the valley floor, valley sides and most tributaries supported by a myriad of roads has undoubtedly had some impact on the rearing capacity of the river. For example, several clear cuts that occurred in the 1970s adjacent to the river have resulted in riverbank instability, undercut banks and sloughing.

Salmonids make extensive use of off-channel habitats that include marshes, ponds and river side channels Lister and Finnigan (*in* Slaney and Zaldokas 1997) that receive flow directly from the river or from groundwater sources. There are several good examples of these adjacent to the Lardeau River that have been isolated for reasons described above. In the lower portion of the river there is evidence of main channel instability as a result of dykes that have been constructed within the active channel, resulting in simplification of the channel and probable loss of rearing habitat. The attraction of creating off-channel habitat is that it provides more stable habitat than the main-stem river and the risk of flooding loss or damage is considerably less.

Cederholm et al. (*in* Slaney and Zaldokas 1997) provides a good summary of the importance of LWD for rearing salmonids. They point out that use of LWD by juvenile salmonids varies seasonally and that LWD is particularly important for over-wintering salmonids to avoid flood-induced mortality. Bustard and Narver (1975) documented that steelhead moved into deeper pools with dense cover as the seasonal water temperature declined. They also noted that movement of steelhead to hydrologically safer side or off-channels likely increased their survival. Irvine (1978b) indicated that Gerrard rainbow trout fry move from shallow, low velocity waters to deeper water (i.e., pools) in the fall and winter months. The fry assessment work on the Lardeau in 2000 and 2002 confirmed the importance of LWD with parr found in close association with deeper (> 1 m) pools formed by logjams. It has been well documented that LWD and deep pools are critically important to steelhead parr and other salmonids that reside in streams for one or more years (see Slaney and Martin *in* Slaney and Zaldokas [1997]). The question is -- how much parr habitat in the form of complex pools and LWD is available to Lardeau River trout, and are they fully utilized?

Considering the noticeable impacts of past linear development and logging in the Lardeau Valley it would seem appropriate to implement some restorative initiatives using the techniques outlined in Slaney and Zaldokas (1997). An overview assessment of restoration opportunities was conducted by Redfish Consulting Ltd. (2001), but no attempt was made to assess the condition or amount of existing habitat. Some specific restoration sites were identified and prioritized. Another outcome of this work was the identification that a more detailed assessment of existing habitat was required. Biophysical river data is required to measure the amount of each habitat strata and allow for diagnosis of the present habitat conditions. The type(s) of habitat that may limit the population needs to be quantified to provide direction for any future restoration work. This data can also be utilized in the future to assist in estimating fry and parr densities to determine their carrying capacity and abundance in the river.

The following report documents on-site measurements and evaluation of Lardeau River habitat characteristics and then integrates this information with that documented by Golder Associates Ltd. (2002) on the lower Duncan River.

SITE DESCRIPTION

Kootenay Lake is positioned in a north-south axis between the Selkirk and Purcell mountain ranges in the southeast corner of British Columbia. At the north end of Kootenay Lake the Duncan-Lardeau rivers are the major inflowing tributaries to the lake. The Lardeau Valley lies in a northwest-southeast position relative to Kootenay Lake and is quite narrow often less than 2 km across the valley floor. The valley widens to about 4 km at the north end of Kootenay Lake, i.e., the Duncan River delta. The Lardeau River forms at the outlet of Trout Lake, approximately 40 km north of Meadow Creek, BC (Figure1). The river flows approximately 40 km in a southeastern direction where it joins the Duncan River near Meadow Creek. The Duncan River flows south about another 10 km before entering the north end of Kootenay Lake. Highway 31 parallels the Lardeau River and is marked by logging sign posts throughout its length with the town site of Lardeau BC Road km 0 and Gerrard marked as Road km 51. For ease of reference sample sites throughout this report refer to road km.

The Lardeau River is a low gradient system varying in grade from 1 to 2% although the spawning area at Gerrard is <0.25% (Redfish consulting Ltd. 2001). Trout Lake serves as a settling basin for the spawning grounds, hence, the water is nearly always very clear. Lardeau River turbidity from erosion and snowmelt is initially evident where Mobbs Creek flows into the Lardeau. Each tributary contributes significant sediments and fines to the Lardeau River during spring freshet. River discharge at Gerrard exceeds 100 $m^3 \cdot sec$ in late June but falls to < 50 $m^3 \cdot sec$ by early July (Hartman and Galbraith 1970). The river is usually turbid from mid-April to early July when it typically returns to a clear flowing state. The first of the tributaries is Mobbs Creek located some 500 meters downstream of the outlet of Trout Lake (Figure 1).

The Lardeau River is fairly active, geomorphologically, with large wood accumulations (log jams), bar development, and bank erosion in some reaches particularly evident. River bank cover is patchy; no cover is common in the large meander areas while mature forest exists in the unlogged riparian and young forest/deciduous dominate in the logged areas. Periodic large meander bend features multiple side channels, with some active, while others dewatered during late autumn flows. Due to a 1% gradient,

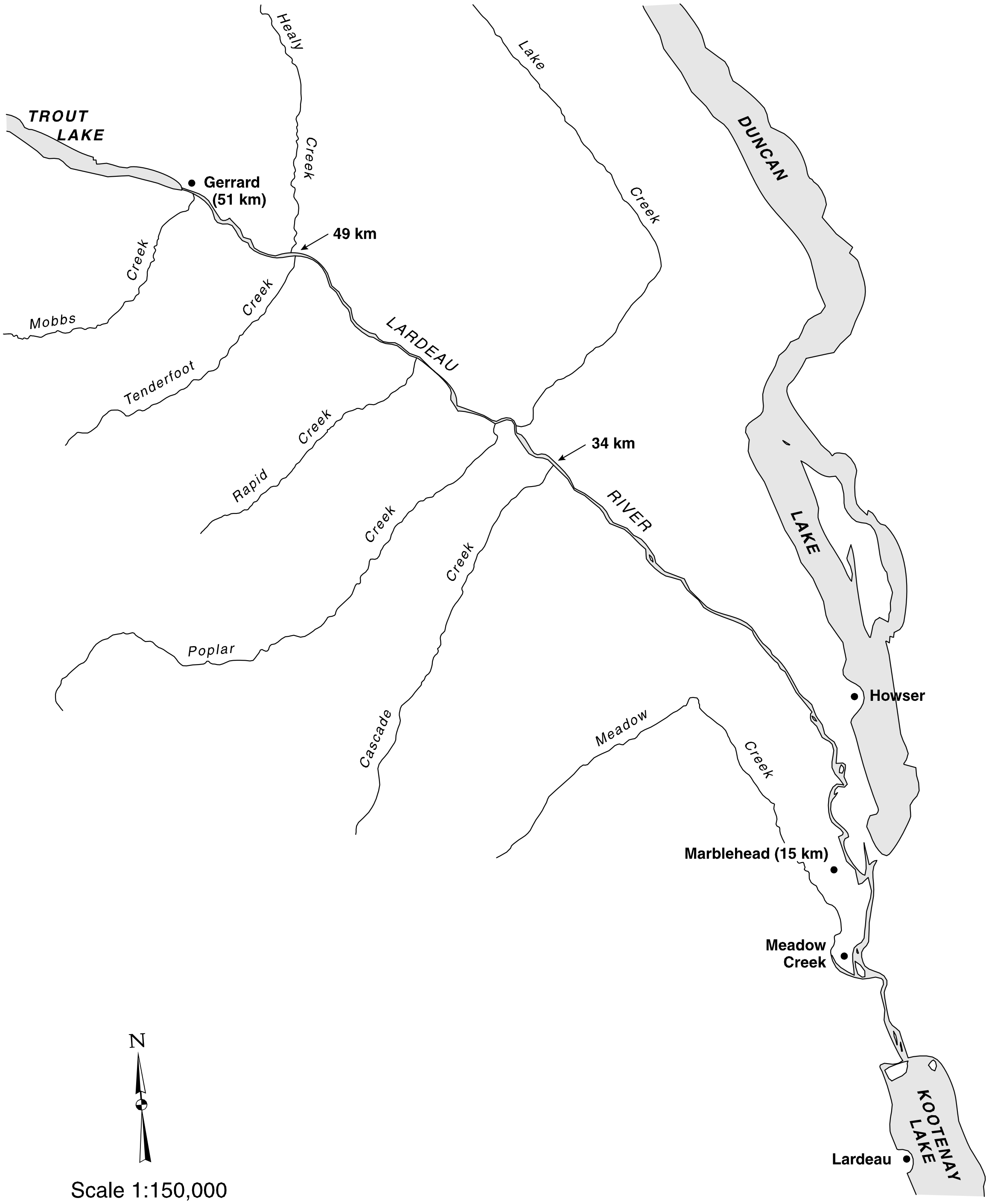

Figure 1. Lardeau-Duncan River system.

long sections of riffles are common, and form log jams creating deep pools and extensive glide areas.

METHODS

1. Physical-chemical Characteristics and Reach Locations:

Recent temperature, water quality and discharge data for the lower Lardeau River were summarized from Environment Canada (discharge), Perrin and Korman (1997) and Golder Associates ltd. (2002).

For easy reference during the field surveys, the river was segmented into six reaches (Fig. 2) of 6.5 to 8.76 km based on road km of 5.5 to 6.5 km indicated by the logging road markers starting at Mobbs Creek (50 km) (Fig.2):

Reach 1 - 50-45 km (start Mobbs Creek)
Reach 2 - 45-39 km
Reach 3 - 39-33 km
Reach 4 - 33-27 km
Reach 5 - 27-21 km
Reach 6 - 21-14 km (end 1 km downstream of Marblehead)

To obtain true river lengths, a planimeter was used to measure the length of the river from 1:250,000 maps, which was 44 km. The measured length was used to adjust reach lengths that were measured from the highway (mean expansion factor 1.18). Thus, reach lengths were 6.4 km (Reach 1), 7.08 km (Reach 2-5) and 8.76 km (Reach 6), or 43.5 km.

2. Fish Habitat Assessment Procedure

The habitat assessment procedure was conducted during late September in 2002. Results are summarized in this report and presented in more detail in Slaney and Andrusak (2003). The fish habitat assessment procedures (FHAP) originated in the Pacific Northwest for quantitatively assessing the effects of past logging activities on forested streams (Schuett-Hames et al. 1994). They were adapted and modified for use in British Columbia (Johnston and Slaney 1996), and ideally they should be applied using diagnostic data collected from old-growth forested watersheds similar to the targeted watershed. Where diagnostic data is unavailable, generic diagnostics are utilized (Table 5 in Johnston and Slaney 1996). Slaney and Andrusak (2003) noted that an evaluation of the technique in a large set of coastal and interior streams of various sizes supported its use in BC, particularly for the large wood diagnostics (Ministry of Water, Land and Air Protection, data on file). The procedure has some uncertainties when applied to large streams, in that it was developed mainly for small to medium sized streams with channel width in the order of 15 m. Thus, there are uncertainties on how well it applies to larger rivers with channel widths of > 15 m. Even though the average channel width of the Lardeau River is about 70 m, it should apply well because the channel and habitat features are very highly influenced by large wood. However, its application to the high-flowing Duncan River may be problematic owing to high release flows that obscure habitat features.

By indicating reaches with declining habitat features, the procedure is also designed to help identify opportunities for restoration or for offsetting impaired conditions and lost habitat. In September 2002, the Lardeau River was sub-sampled over 20% of its length by random selection of 1-2 km sub-sections within six reaches (Fig. 2). Lengths of the six reaches ranged from 6.4 km (Reach 1) to 7.1 km (Reach 2-5) to 8.8 km (Reach 6). According to the methodology, hydraulic units were separated in to riffles, glides, and pools and prescribed physical characteristics were measured with a metric rod and a laser range finder, the latter accurate to + or - 1.0 m. Parameters measured included lengths of hydraulic units (riffle, glide, pool), bankfull width, wetted width, bankfull depth, mean wetted depth, maximum pool depth, and residual pool depth.

Consensus estimates (by the authors) on several other features were made to minimize error. These variables included dominant substrate size, sub-dominant substrate size, gradient, surface velocity, percent total cover, percent boulder cover, percent large woody debris in pools, and cover types per habitat unit.

Total large wood was counted within the bankfull channel as all wood >2 m in length and > 10 cm in diameter. Functional large wood was that which influenced the nature of the hydraulic units in terms of scour and cover, and it was counted by size category according to basal diameters of 10-20, 20-30, 30-40, 40-50 and >50 cm.

In the riparian zone on each bank, dominant trees were classified as pole sapling (including shrub), young forest, and mature forest, or roadway. The zone was also classified as deciduous, conifer or mixed structure, and the percent canopy closure over the river was estimated. Linear length of river cut off by Highway 31 was measured by recording the vehicle odometer for those sections that were > 100 m. Visual estimates of smaller sections < 100 m were also recorded.

Values of the various parameters were converted to those required for diagnostics as: percent pool (by area), pool frequency or spacing per channel width, total and functional large wood per channel width, percent woody debris in pools, percent boulder cover in riffles, percent total cover and substrate quality. Side-channel development of the floodplain and dissolved nutrient concentrations in summer were also rated.

A similar protocol was followed for all side-channels encountered in the 1-2 km sampled segments of the six mainstem reaches.

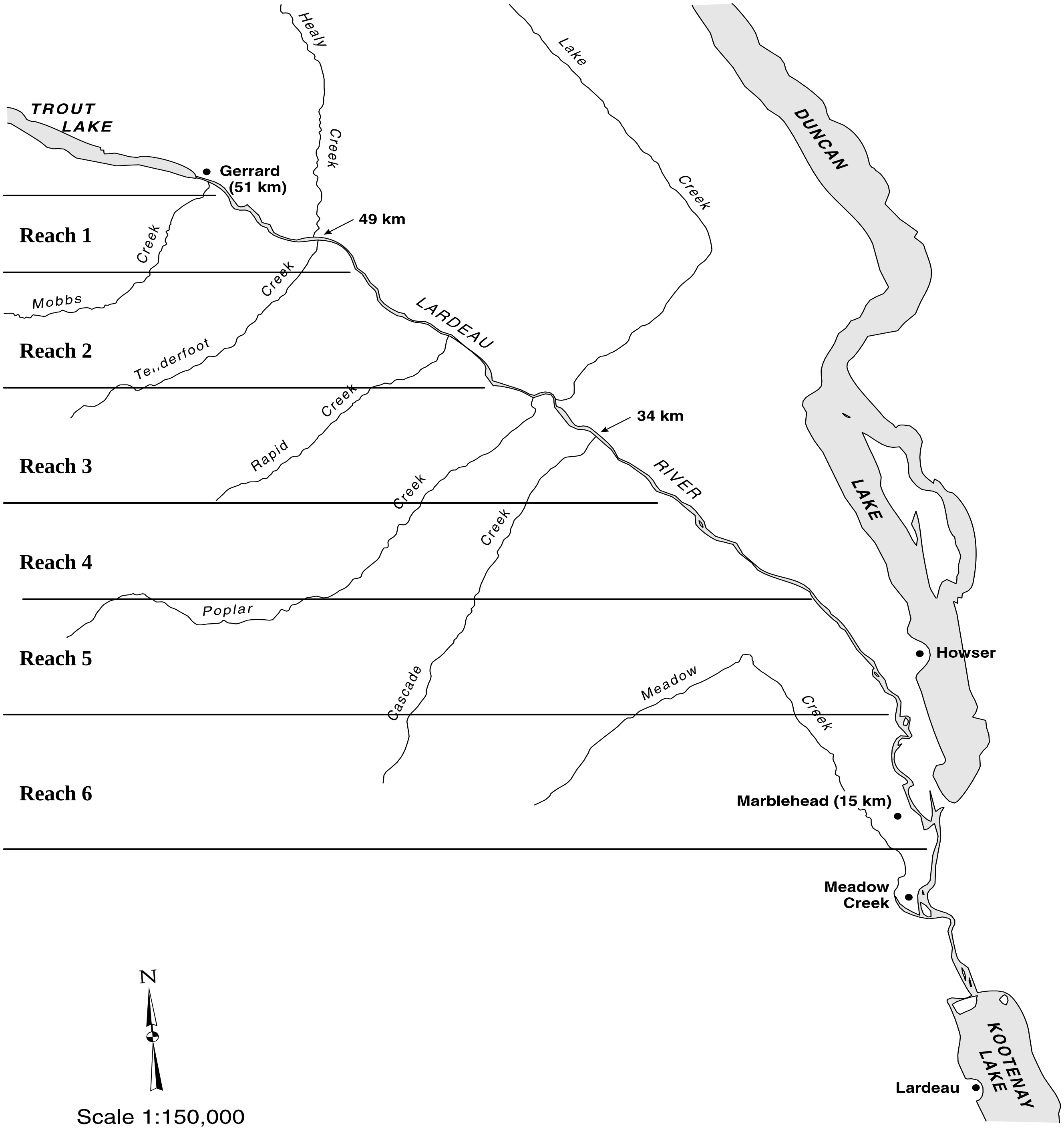

Figure 2. Reach locations at the Lardeau River.

3. Preliminary Habitat Capability Modeling

The life history of Gerrard rainbow trout has striking similarities to steelhead trout, a feature noted by Irvine (1978a,b). Large adult trout of a similar size range to some steelhead stocks ascend the Lardeau River and spawn where the spawning habitat is most suitable. Fry disperse downstream and fill rearing habitat similar to steelhead but unlike most other resident rainbow stocks, which rely heavily on smaller tributaries for spawning and rearing to age 1+ and 2+ (Slaney 1987; Burrows 1993). Lardeau River tributaries are believed to be too cool and steep (Irvine 1978b). Therefore, smolt or parr production models developed for steelhead (Slaney 1981MS, Lirette et al. 1987) should be applicable to Gerrard rainbow.

Habitat Units and Useable Areas

Within the sampled reach sections of the mainstem of the Lardeau River, hydraulic units measured as part of the FHAP were stratified further from three into five habitat units comprised of riffles, glides, pools, runs and flats. Definitions of the habitat units are based on the Keogh River in spring and are as described in Table 3 of Lirrette et al. (1987) and in Slaney (1981MS). For example, gradients in riffles were > 0.2%; in pools and flats the grade was near zero, whereas in glides and runs they were intermediate. Width to maximum depth ratio in riffles was high (24:1) versus low in pools (8:1) and runs (9:1), and intermediate in glides (or flat-runs: 15:1) and flats (18:1). Further, turbulence was used to separate habitat units, using the Keogh River features as the template- surface turbulence averaged 75% in riffles and 45% in runs, 25% in glides, up to 20% pools, and < 6% in flats. (Note: glides are equivalent to flat-runs as described in Slaney [1981MS]). These criteria were used to assist in classifying and separating macro-habitats as discrete habitat units in the Lardeau River.

Model variables were measured by laser range finder in late September (2002) and included length to the nearest m and wetted width to the nearest m. Depths were measured with a wading rod marked in 10 cm intervals. Variables estimated by consensus were percent total overhead cover, which comprised of all significant salmonid cover including overhanging vegetation with 1 m of the water surface, cutbanks, and large woody debris (LWD). Also estimated were percent boulders in the wetted area, comprised of protruding boulders > 30 cm in diameter. The latter were estimated by blocking out areas and measuring their lengths and widths, then summing their areas over the unit. These two variables in riffle habitats explained 87% of the variance in steelhead parr density in early summer the Keogh River (Slaney MS 1981).

In addition, within each hydraulic unit, percent useable fry and parr habitat was estimated by measuring and estimating sub-sections lengths and widths, and calculating approximate areas, based on IFIM weighted useable depth and velocity criteria for trout fry and parr (“Delphi” curves obtained from R. Ptolemy per comm. 2002).

Parr Production Modeling

A steelhead smolt production model was used to estimate parr production from the Lardeau River to gain insight into habitat productivity. The model is based on parr density-habitat relationship in riffles plus mean densities in other habitats of the Keogh River, which are then adjusted by TDS (as surrogate for nutrient regime in summer), and proportionally by water temperature. Because the model calculates smolt production by use of constant survival of 0.4 from parr to smolt, the model was adjusted to calculate parr. This was accomplished by dividing the smolt value of $0.02/m^2$ by 0.4 which is 0.05.

The adjusted equation was:

Equation 1: $\text{Parr} = H_p (N_p/0.05) (T/9)$

- where parr = numbers of rainbow trout parr in the river by spring, prior to a portion migrating at age 1; and
- where H_p = annual parr density; and
- N_p is an adjustment for nutrient level using TDS as a surrogate such that:

Equation 2: $N_p = 0.00049x + 0.0037$

- where x = TDS in mg/L, 0.05 is a constant as the mean parr density at Keogh River; and
- T = the mean annual river temperature (unit-less), with 9 as a constant, as the mean annual water temperature of the Keogh River.

The parr production equation was:

Equation 3: $H_p = (P_{ri} + P_{ru} + P_{po} + P_{gl} + P_{fl})*(U_p)$

- where P_{ru} = mean parr density in runs, P_{po} = mean parr density in pools, P_{gl} = mean parr density in glides, and P_{fl} = mean parr density in flats; and
- where U_p = useable m^2 of parr habitat per reach of the Lardeau River (as defined in the next).

For each of the habitat types the mean parr numbers were then derived by:

Equation 4: $P_{ri} = (0.0029b + 0.0031c – 0.004)$

- where P_{ri} = mean parr numbers in riffles, and b = percentage of wetted area of riffles comprised of protruding boulders >30 cm diameter; and c = percentage of wetted area of riffles comprised of over-stream cover (woody debris, cutbanks, vegetation) ($r^2 = 0.7$)

- with $P_{ru} = 0.11$, and $P_{po} = 0.064$, and $P_{gl} = 0.074$, and $P_{fl} = 0.017$; and

- where P_{ru} = mean parr density in runs, P_{po} = mean parr density in pools, P_{gl} = mean parr density in glides, and P_{fl} = mean parr density in flats.

Mean densities were used because the r^2 values for various cover parameters were < 0.5, but difference in densities were significant ($P<0.05$; $n = 118$).

The steelhead model was based on the Keogh River where parr production is limited by the amount of parr habitat in summer. The full width of the Keogh River is useable in late spring to early summer by parr, in contrast to larger streams or rivers including the Lardeau where only a small proportion of the wetted width in summer to fall is useable by parr and fry, owing mainly to excessive velocities. To adjust for unusable areas of the river, the area of each surveyed habitat unit was multiplied by the estimated useable proportion of parr area of that unit.

Within each hydraulic unit, percent useable fry and parr habitat was estimated by determining sub-section(s) lengths and widths, and calculating approximate areas, based on IFIM weighted useable depth and velocity criteria for trout parr ("Delphi" curves obtained from R. Ptolemy per comm. 2002). It should be noted that based on measurements made at the Capilano River in the fall 2002 it was known that visual estimates underestimated useable fry habitat derived from measured depths and velocities but similar for parr estimates (data on file).

Similarly, fry habitat was also estimated to assess if there was sufficient fry habitat area to support model estimated parr production. This comparison was made by two means: (1) applying an estimated survival rate from a measured fry densities within the Lardeau River from Irvine (1978b) and Redfish Consulting Ltd. (2002); and, (2) by comparing field estimates of useable areas to published measurements of areas per fry and parr and territory areas of fry and parr to determine if fry habitat was in excess. Territorial areas were obtained for fry from Slaney and Northcote (1974) and Allen (1969).

The modeling exercise was set up on a spreadsheet, with calculation sequences as follows:

1. the length and wetted width of a habitat unit was used to calculate wetted area (m^2) of the habitat unit;

2. the area was multiplied by the estimated proportion of useable parr (nearest decimal) to obtain useable area of parr habitat (m^2);

3. for each riffle per reach, the riffle equation above is applied to obtain the predicted parr density (no./ m^2);

4. the riffle parr density is multiplied by the useable parr area to obtain the predicted numbers of parr from each riffle as per Equation 3 and 4;

5. for each glide, pool, run and flat the constant as a mean density from the Keogh River (n = 110) is multiplied by the useable parr area for each respective habitat unit (no./ m^2 in glides, pools, runs and flats) to obtain the predicted numbers of parr from each glide, pool, run and flat as per Equation 2;

6. respective numbers per unit as H_p are then adjusted for nutrient status using Equation 2 with Equation 1. TDS (as mg/L) applied was proportionally applied along the river where TDS data was lacking as 102 (Reach 1), 97.4 (Reach 2), 92.8 (Reach 3), 88.3 (Reach 40, 83.7 (Reach 5), 79.1 (Reach 6) and 69.4 (Duncan); and

7. parr production is also proportionally adjusted for water temperature (see data description below), which in the upper Lardeau was slightly greater than Keogh River while in the lower Lardeau River it was lower than Keogh. Water temperatures (as ^{o}C) were proportionally applied where temperature data was lacking were 9.2 (Reach 1), 8.9 (Reach 2), 8.6 (Reach 3), 8.3 (Reach 4), 8.0 (Reach 5), 7.7 (Reach 6), and 6.5^{o}C (lower Duncan).

TDS at Gerrard was from lake limnological data files of Trout Lake, and from Perrin and Korman (1997) for Marblehead (Reach 6) and lower Duncan River.

Despite the relatively large amount of study on the Lardeau River there was sparse annual water temperature data available. Cartwright (1961) provided some temperature data from May-August 1958 for four stations along the length of the river. At Gerrard, spring (May-June) temperatures gradually increased to 10°C and rose to nearly 20°C by mid August. Mid river temperatures were slightly lower and at Marblehead the summer temperatures seldom exceeded 15°C. Cartwright (1961) observed that the glacial fed tributaries tended to reduce the river temperature the length of the river. Acara (1970) showed that the late winter (March) temperature was nearly identical (≈ 1.5°C) at Gerrard and Marblehead but by May the temperature at Marblehead was consistently 1.5°C lower than at Gerrard until September when the difference narrowed to about 1°C. Summer temperatures from Gerrard downstream to Marblehead recorded by Andrusak and Baxter (2000) also showed a gradual decrease from the upper to lower portions of the river. In August 2000, the difference was 4°C while in September it was 2°C. In 2002, the difference during the September fieldwork was only 1.5°C. Perrin and Korman (1997) recorded monthly temperatures at Marblehead in 1994-1995 and determined the mean annual temperature was 7.7°C while the lower Duncan River was 8.0°C. Since the upper reaches of the Lardeau River are warmer than the lower reaches during the growing season (May-October) it is reasonable to assume that the mean annual temperature in the upper river is at least 1.5°C higher.

Duncan water temperatures were more problematic than Lardeau because of shifts induced by deep (35 m) withdrawal from the reservoir in front of the Dam (DVH Consulting 2001). This provided relatively cool temperatures in summer and warmer temperatures in winter than in the Lardeau River. Because parr production results largely from the primary salmonid growth season, the measured temperature reported by Perrin and Korman (1997) was adjusted to equated to winter conditions of 1.5°C (similar to the Lardeau). Temperatures were re-averaged using 1.5°C from December to March, and the measured temperatures from April to November (October and November were not available above and they were assumed to be 10°C and 7°C, or similar to the upper Lardeau near Gerrard.). Thus, the temperature utilized in the parr production model for lower Duncan River was 6.5°C or about 1.2°C less than lower Lardeau River.

RESULTS AND DISCUSSION

1. Historical Information

Hydrology and Water Temperatures

The Lardeau River drainage represents approximately 35% of the total catchment area that drains into the north arm of Kootenay Lake via the Duncan River with the Duncan River system contributing just over 51% (Perrin and Korman 1997). The lower Duncan River is a regulated system influenced by discharges from the Duncan Dam that has essentially reversed the natural hydrograph with bimodal peaks now evident in August and late winter compared to the typical peak pattern that occurs in unregulated systems in the spring months (DVH Consulting 2001). The Lardeau River is unregulated, displaying a typical peak runoff in May-June with flows remaining relatively constant from mid summer through to early spring. The mean annual discharge is 59 m^3·sec with late summer-fall flows typically < 40 m^3·sec (Fig. 3).

Water temperatures at Marblehead from 1968-1972 ranged from 0.6-13.6°C but temperatures at this location tend to be much colder than the upstream portions of the river due to the cooling effect of several glacial tributaries (Irvine 1978b). Hartman and Galbraith (1970) also noted that water temperatures at Gerrard were warmer in the spring-summer months compared to downstream sites and Redfish Consulting Ltd. (2000) reported a temperature gradient along the river in August-September 2000. Periodic recording of temperatures at Gerrard and Marblehead throughout the summer months (2002) showed that at Gerrard the water was usually 3-4°C warmer than at Marblehead. Perrin and Korman (1997) reported the mean annual temperature at Marblehead was 7.7°C (± s.e. 0.9).

Water Quality and Nutrients

Water quality data for the Lardeau River system is limited with the most updated information provided by Perrin and Korman (1997) for all seasons in 1994-1995 and for September 1998 reported in Golder Associates Ltd. (2002). A few select parameters are provided in Table 1. One important difference between the Lardeau and Duncan Rivers is the contribution of total phosphorus (TP). The Lardeau system contributed 77% while the Duncan only 23% with much of the difference due to load retention of PP in the Duncan Reservoir (Perrin and Korman 1997; K. Ashley, UBC Limnologist, pers. comm.).

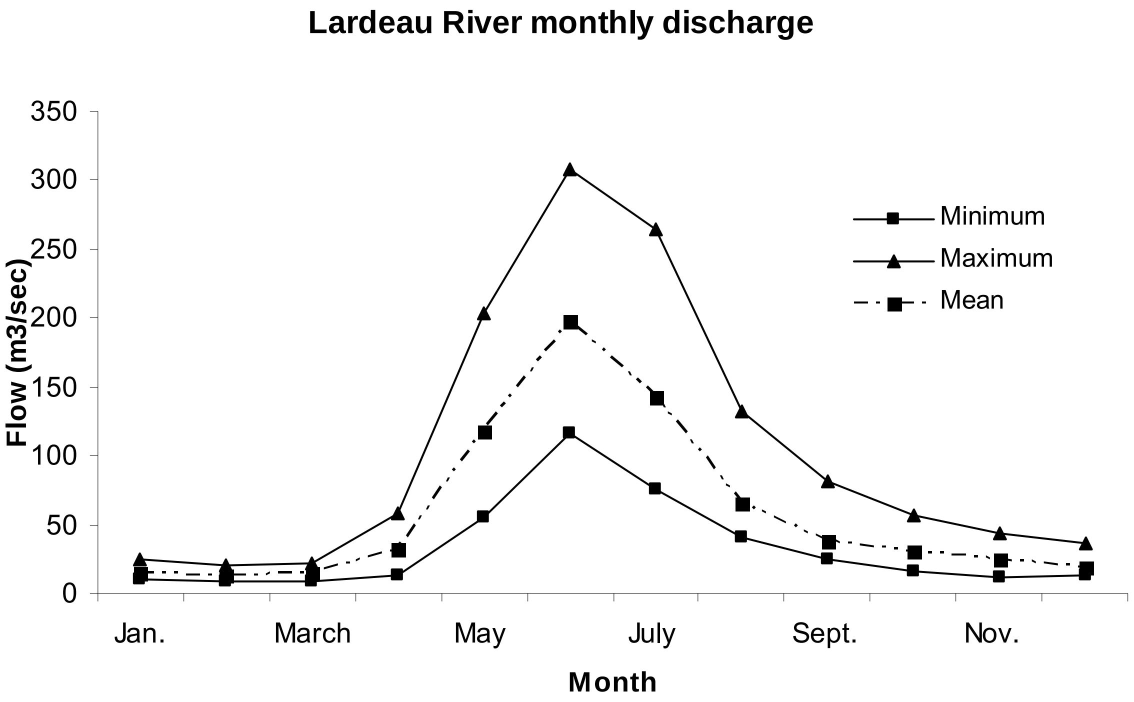

Figure 3. Lardeau River monthly discharge in m3/sec recorded at Marblehead 1916-1996.

Table 1. Select water quality parameters for the Lardeau River and lower Duncan rivers 1994-95 (Perrin and Korman 1997) and September 20 1998 (Golder Associates Ltd. 2002).

Parameter	**Lardeau River Values**		**Lower Duncan River**	
	1994-1995	**1998**	**1994-1995**	**1998**
pH	8.4	7.98	8.4	7.75
TDS Lardeau River	79.1	83	69.4	44
TDS Gerrard (Trout L.)	102			
Conductivity	118.7	139	104.1	75
Total alkalinity ($CaCO_3$)	61.9	68	49.3	33
Hardness		73.1		41.7
Turbidity (NTU)	4.3		10.1	
Temperature	7.7		8.0	

Nutrient data from Perrin and Korman (1997) indicate that during the summer in the Lardeau River and Duncan River (the latter above the confluence), mean dissolved NO_3-N concentrations are 78 µg/l and 150 µg/l, respectively, and thus nitrate nitrogen is not limiting autotrophic production. However, in the Lardeau River, mean dissolved SRP and Total P are 0.9 µg/l and 1.7 µg/l, respectively, and the molar mean N:P ratio is high (211). Thus, P is significantly limiting autotrophic production. In the Duncan River, mean dissolved SRP and Total P are 0.5 µg/l and 1.7 µg/l, respectively, and the mean molar N:P ratio is extremely high (719). Thus, autotrophic production and the insect-fish food chain is highly limited in the Duncan River by very low SRP concentrations associated with extremely low molar N:P ratios. Summer concentrations SRP concentrations < 1 µg/l are rated as “poor” or deficient (Johnston and Slaney 1996, Ashley and Slaney 1997).

Gerrard Rainbow Trout Escapements

Irvine (1978b) provides a lengthy summary of the history of fisheries involvement at Gerrard, the only known location for spawning by the unique strain of Kootenay Lake rainbow trout. This population has been visually enumerated since 1957 and the shore-based spawner counts have been used as an index of abundance. This population has fluctuated over the last five decades due to a combination(s) of intensive fishing pressure (Redfish Consulting Ltd. 2002) and numerous ecological changes. The major cumulative impacts include:

- over zealous egg collections in the 1940s and 1950s (Irvine 1978a);
- short term cultural eutrophication of Kootenay Lake (Northcote 1973, Daley et al. 1981);
- impacts of Duncan and Libby dam on kokanee numbers;
- stocking of yearling Gerrard rainbow trout in the 1980s (Redfish Consulting Ltd. 2002);
- oligotrophication of the lake in the 1980s (Ashley et al. 1997); and
- experimental fertilization of the lake in the 1990s (Ashley et al. 1997).

All of the impacts are reflected in the escapement data (Fig. 4). The current downward trend in the population is believed to be due to some over fishing in the late 1990s and a decline in kokanee numbers as a result of deliberate scaling back on lake fertilization in the latter part of the 1990s (Redfish Consulting Ltd. 2002; Andrusak 2002). There is uncertainty as to whether or not the Mobbs Creek debris torrents will have any impact on numbers of adults.

Despite the various impacts on this trout population the fluctuations in abundance have not been extreme especially once the population rebuilt from the over exploitation of spawners for eggs in the early 1950s. Conservation and maintenance of this wild population of rainbow trout has been highly dependent upon careful management of the sport fishery as well as retaining and protecting the natural habitat of the Lardeau River. A vigilant habitat protection strategy has been in place for the last four decades and the river to this day is comparatively intact. Any impact on the Lardeau River due to human and/or natural events has always been a concern to fisheries managers, First Nations and the public. Natural debris torrents that originated in the Mobbs Creek watershed in November 1999 and May 2000, May 2001 and April-May 2002 that flooded some or all of the Gerrard spawning grounds for short periods of time are alarming. The Ministry of Water, Land and Air Protection (WLAP) fisheries staff in Nelson immediately responded to last three spring events by excavating the debris jams to restore the natural flow of the Lardeau River. The 2002 emergency work involved excavation of a number of redds that had been developed at the confluence of river and Mobbs Creek (R. Gates, Gerrard River Guardian, pers. comm.).

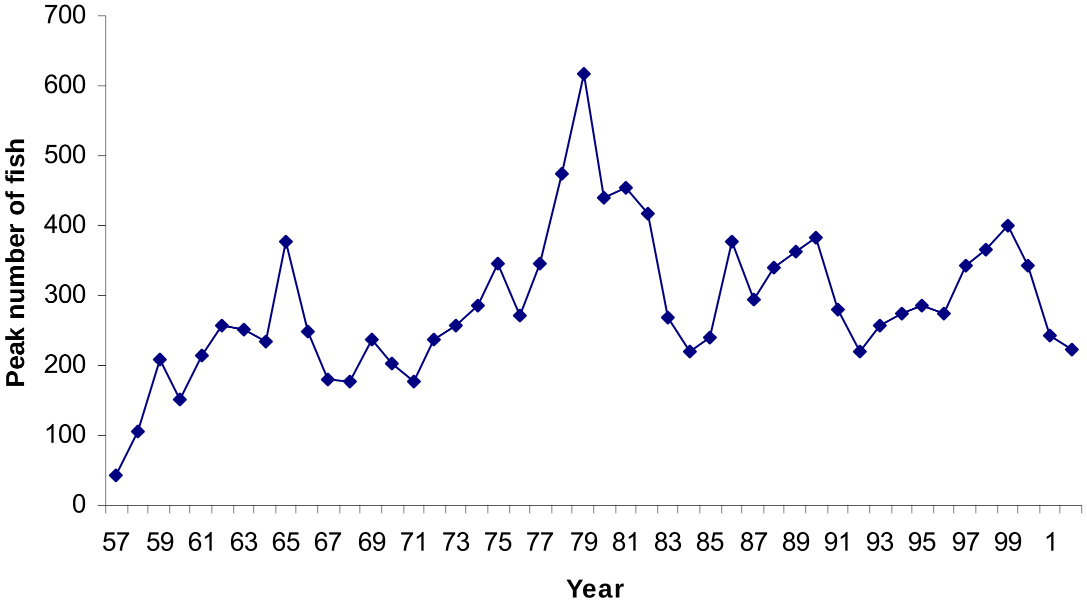

Figure 4. The daily peak count of Gerrard rainbow trout spawners 1957-2002. Dotted line indicates 46 year average (287).

Egg Deposition and Fry Production Estimates

The only investigative work on Gerrard rainbow trout production is that of Irvine (1978a,b) although Hartman (1969) and Hartman and Galbraith (1970) described the spawning habitat and spawner requirements in some detail. Acara (1969 unpubl. MS) estimated the number of spawners that moved through a fish fence located at Marblehead in 1966 and 1967. The ratios of fish counts at the fence versus counts at Gerrard were used by Irvine (1978a) to forecast numbers of spawners in years prior to and after those years based on the shore counts at Gerrard.

Irvine (1978b) generated a regression formula for Gerrard female trout based on actual egg counts from 35 females captured in 1966. He estimated the average fecundity was 8,076 and calculated egg deposition per female at 7,268 based on some egg retention observations by Acara (1969 unpubl. MS) and egg predation and displacement estimates by Hartman and Galbraith (1970). He also used a sex ratio of 1 female per 1.3 males based on hatchery records from 1913-1952. Average potential egg deposition for the years 1967-1976 was estimated by Irvine (1978b) based on the derived fecundities, measured egg loss (retention + predation) and known sex ratio. An egg-to-fry survival rate of 50% was applied to calculate the average number of emergent fry or 785,000 fry annually. Acara (1969 MS) estimated about 108,000 fry migrated by the fish fence at Marblehead, and Irvine felt that the majority of the fry produced from Gerrard occupied the available rearing habitat of the Lardeau River and its side channels with high natural mortality occurring over the summer as the fry numbers approximate the carrying capacity of the river. Based on his fall fry density estimates Irvine estimated that about 97,500 fry were rearing in the river in October and that about two-thirds (65,000) of these survived to lake migrant size in the spring.

The crude estimates of fry and smolt production by Irvine (1978b) are based on some good biological data and numerous, reasonable assumptions on survival rates from eggs to smolt production. There has been no biological data collected since Irvine's work that can be used to further refine either the egg deposition estimates or the fry and smolt estimates other than some crude estimates of fry densities generated by Redfish Consulting Ltd. (2002). However, the estimate of summer fry and over-wintering parr can be revisited if the amount of fry and parr habitat is assessed. Irvine did not have such data and he had to base his estimates on fall fry densities and observations (swim and electroshocking) that juvenile trout were restricted to the river margins that he assumed were 1.5 m wide.

Since it is believed that this trout population is limited by available rearing habitat a more accurate estimate of available rearing habitat is a first step in improving upon Irvine's original estimates of fry and parr numbers. An attempt to estimate such numbers based on estimated habitat types is made later in this report.

Juvenile Trout Size-at-Age

Irvine (1978a,b) assigned ages to the juvenile trout based on scale analysis and suggested that those < 100 mm in the fall were age 0+ and those > 100 mm were age 1+ or older. The length-frequency histograms generated for Fall 1974 and September 2000 and 2002 all show two modes with age 0+ largely between 40-60 mm and older fish > 90 mm (Fig. 5). Mean size of September 2000 fry (< 90 mm) was 53.6 (n=53, 1 s.e. = 1.1, 1 s.d. = 7.6) while in September 2002 the mean was 50.7 (n=155; 1 s.e. = 0.6, 1 s.d. = 6.8). Mean size in the fall 1974 was 62. 0 mm and since these fish were sampled a month later (October) the larger size is not surprising. Irvine (1978a) suggested that juveniles grow 12.5 mm per month; thus, the fish sampled in 2000 and 2002 would be of similar size to those sampled in 1974.

Habitat Assessment Results of 2002 (FHAP)

Results of the fish habitat assessment procedure are provided in detail in Slaney and Andrusak (2003). These results are summarized in this report to emphasize trends in impacts that need to be accounted for in any future production capability estimates of Gerrard rainbow trout. For a more detailed summary of mean widths, depths, dominant and sub-dominant substrates, estimated gradient, estimated velocity, and riparian vegetation types and canopy closure see Slaney and Andrusak (2003).

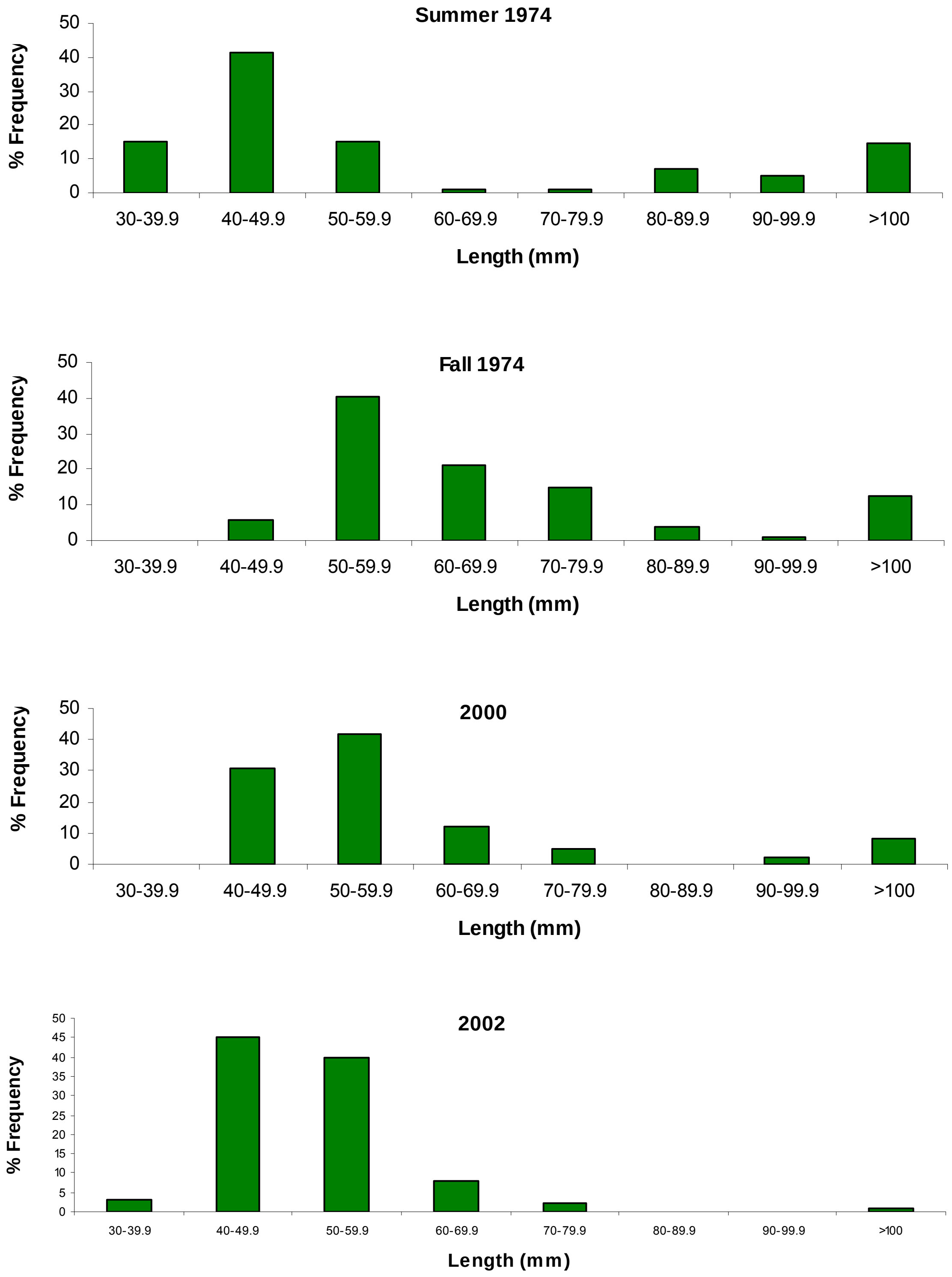

Figure 5. Length frequency histograms of Lardeau River juvenile trout captured by electrofishing throughout the river 1974, 2000 and 2002. The 1974 data is from Irvine (1978) and includes parr whereas 2000 and 2002 sampling was focused on fry habitat only. The Fall 1974 data most comparable with September 2000 and 2002 data.

Twenty percent of the length of the Lardeau River was sampled, with sampled lengths ranging from 1021 m in Reach 4 to 1,671 m in Reach 1. Reach sample locations were as follows:

Reach 1, 45-46.7 km (lower) lat. 50 29 476, long. 117 14 988 W;
Reach 2, 42-43.5 km, lat. 50 27 029 N, long. 117 10 882 W;
Reach 3, 38 km (lower), lat. 50 25 479 N, long. 117 08 595 W;
Reach 4, within 27-32 km, lat 50 21 899 N, long. 117 02 858 W;
Reach 5, 24.2 km (end) (no gps record);
Reach 6, 20-21km, lat. 50 17 814, long. 116 58 154 W.

Sub-sampled total length was 8.3 km of the Lardeau River.

One substantial impact not described elsewhere is a significant loss of riparian area associated with the railway/roadway. The degree of riparian canopy alteration that has been exposed was measured along Highway 31 for the length of the river. No measurements were recorded on the opposite side of the river from the Highway since riparian habitat there has only been impacted by floodplain logging (except for 0.2 km at one farm site at Marblehead). Along Highway 31 the riparian habitat has been reduced to bare cover (< 1 tree) by nearly 30%, a few fringe trees (< 20 m in height) by nearly 16% with forest cover (well-treed) for about 55% (Table 2). Highway 31 was the primary reason for this condition with some minor impacts due to farming (near Poplar Creek and Marblehead) and roadway clearance for visibility at bridge crossings. Thus, almost one half of the river's riparian area along the Highway was completely bare of trees or had a mere fringe of trees. A riparian zone denuded by nearly 50% on one side of the river is significant in reduced recruitment of large woody debris. Furthermore, overhead cover as well as insect drop from vegetation would be seriously curtailed over at least 30% of the river length.

Table 2. Extent of Lardeau River riparian habitat cover measured in lineal km on September 24, 2002. (Road km = open, fringe km = < 20 m treed, treed km > 20 m treed.)

Reach	Road km	Open km	Fringe km	Treed km
1	50-45	2.1	2.0	2.7
2	44-39	2.3	1.0	2.9
3	38-33	1.6	0.9	2.0
4	32-27	2.0	0.9	2.9
5	26-21	0.9	0.0	4.4
6	20-14	1.1	0.6	3.7
Total (%)	**34 km**	**10.0 (29.4%)**	**5.4 (15.9%)**	**18.6 (54.7%)**

The extent of river bends cut off by railway construction (now highway) was also documented. As expected, the river sections most impacted were in the upper portion of the valley, which is quite narrow. A total of 2.92 km of cut-off channels were measured in Reaches of 1 (2.12 km) and Reach 2 (0.8 km) with no other cut-off channels evident in the lower portion of the river. Unfortunately, the cut off distance of 2.92 km accounts for about 10% of the total channel length estimated for the entire Lardeau River, and for 50% of the existing side-channel length in the upper two reaches, which is the more productive portion of the river. It should also be noted that at the bridge site on the Lardeau River near the Howser turnoff a large section of the river has been confined for nearly 0.25 km with heavy rip- rap and as result a large side channel (≈ 0.75 km) has been orphaned.

Bankfull width varied considerably between the reaches. Reaches 1, 4, 5 and 6 were relatively narrow, but as expected increase with river length and tributary flow inputs, or 46 m, 62 m, 61 m and 72 m, respectively. However, Reach 2 and 3 were anomalous in this pattern because they were about 1.5 to 2-fold wider on average, or 93 and 107 m, respectively (see Tables 1-5 in PSLaney Aquatic Science Ltd. 2003). Very large bars were evident in these two reaches, yet wetted widths were narrower, similar to Reach 1. Overall, mean channel width of the Lardeau River was 72 m, almost twice the mean wetted width of 39 m, which ranged from 31.5 m to 45.7. This reflected significant bar development in these two reaches, yet of note, they had relatively narrow wetted widths of 37.5 m and 31.5 m with low standard deviations of 13.1 and 9.9, respectively. Average length per hydraulic unit among the six reaches was 117 m and ranged from 77 m in Reach 1 to 159 m in Reach 6. Standard deviations ranged from 37 in Reach 1 to 135 in Reach 4. Mean riffle, glide and pool depth was 0.7, 1.0 and 2.0 m, respectively. Average dominant and sub-dominant substrate sizes were 0.22 m and 0.18 m, respectively, and average estimated gradient was moderate at 0.42 % (range 0.24 in Reach 6 to 0.63 in Reach 4). The velocity averaged 0.60 m/sec (range 0.43 in Reach 6 to 0.70 in Reach 4).

It is likely that channel widening has occurred in Reaches 2 and 3 as riverbanks have lost old-growth root development, and Reach 4, with a high standard deviation on reach length, may have been simplified, aside from small boulders in the substrate, by historical log drives.

Large Woody Debris (LWD) Frequency

Large wood was abundant throughout the Lardeau River. However, much of this wood was lodged high on bars with limited functionality, both hydraulically and biologically, although important geomorphologically for bar stabilization and re-vegetation over the long term (Table 3). More large wood was evident in pools (52%) than riffles (33%) and glides (19%). In Reach 4 in particular, large wood was dominant (70%) in pools, yet riffles comprised 89% of this reach. This reach also had the lowest amount of large wood. Total counts of large wood per channel width, whereby jams are standardized as 10 pieces of LWD according to the procedural protocol, were: 4.5 in Reach 1; 28.8 in Reach 2; 38.3 in Reach 3; 8.1 in Reach 4; 5.0 in Reach 5; and, 10.3 in Reach 6. These are all > 2 pieces of LWD per channel width, which is the threshold that is classified as "good" from the diagnostics of the procedure (Table 5 in Johnston and Slaney 1996). Nevertheless, in large systems similar to the Lardeau River, functional large wood, which does include significant bar wood that has only limited influence on the hydraulics of the channel, should be utilized as the primary diagnostic.

Table 3. Total large wood tally by Reach and percent composition in riffles glides and pools in the Lardeau River in 2002.

	% Composition of Total LWD			Total No. LWD/Chan.
Reach	**Riffles**	**Glides**	**Pools**	**Width**
1	32.1	19	48.9	5.1
2	52.5	5.8	41.6	39.8
3	18.1	44.8	37	85.7
4	29.8	0	70.2	21
5	35.2	6.3	58.5	17.4
6	32.7	11	56.2	24.1
Mean	33.4	18.6	52.1	38.2

In all six reaches, total functional large wood was above the “good “rating of > 2 pieces per channel width (Table 4). Reaches 2, 3 and 6 were well above > 2 per channel width. Reach 4 was 2 above, but Reach 1 and 5 were only about 1 above the threshold (2/channel width) of the “good” rating. Amongst wood that occurs naturally in streams, larger sizes provide much of geomorphic and hydraulic functions, and mean diameter of large wood increases with stream size (Bisson 1992). Large wood that is small (< 30 cm) plays a minor role in the Lardeau River except as cover and as driftwood that adds to the larger and key pieces that form log jams. Of functional wood, small wood < 30 cm basal diameter comprised 48% in Reach 1, 62% in Reach 2, 50% in Reach 3, 44% in Reach 4, 55% in Reach 5 and 55% in Reach 6., or on average 52% per reach.

Table 4. Number of pieces of functional large wood per channel width (CW) by size category (diameter) in Lardeau River in 2002.

Reach	Functional LWD/CW 10-20 cm	Functional LWD/CW 20-30 cm	Functional LWD/CW 30-40 cm	Functional LWD/CW 40-50 cm	Functional LWD/CW >50 cm	Functional LWD/CW Total
1	0.6	0.9	0.7	0.3	0.6	**3.1**
2	3.6	3.3	1.8	0.6	1.9	**11.1**
3	1.4	4.3	2.6	1.2	1.9	**11.4**
4	0.8	1.1	0.9	0.6	0.9	**4.3**
5	1.2	0.6	0.5	0.7	0.3	**3.3**
6	1.2	1.7	1.1	0.5	0.8	**5.3**

When the small pieces (< 30 cm – basal diameter) of functional wood are excluded from analysis, the numbers per channel width are: 1.6 in Reach 1, 4.2 in Reach 2, 5.7 in Reach 3, 2.4 in Reach 4, 1.5 in Reach 5 and 2.4 in Reach 6. From this perspective, Reach 1 and Reach 5 would rate only "fair", and Reach 4 would be close to the "fair-good" threshold of 2. However, Reaches 2, 3 and 6 would rate strongly within the good rating (Fig. 6). If only large wood > 40 cm is included, reach 2 and 3 still rate highly, but other reaches are below the "good" threshold of 2 per channel width. Overall, these results indicate the frequency of functional large wood rates as "good", but when the small wood < 30 cm basal diameter (or second growth) is excluded, three of the six reaches only rate "fair" or "near-fair" (Fig. 6).

A tally of logjams of > 10 pieces of large wood per jam was completed in the sampled 1.0-1.7 km reaches of the river. Two jams were observed in Reach 1, 4 in Reach 2, 4 in Reach 3 (including 3 in a series), 3 in Reach 4, 2 in Reach 5 and 5 in Reach 6. Expanded estimated total jams per reach were 8, 18, 22, 21, 12 and 28, respectively, or an estimated total of 109, or 2.5 per km. Some jams were connected in a series (3 in Reach 3), and the expansions may overestimate actual logjams. Further downstream in the Duncan River, logjam formation has been terminated by the Duncan Dam, but its large tributaries, particularly Lardeau River and, to a smaller degree Cooper and Hamill creeks continue to provide significant wood to the lower Duncan River. Logjams are strikingly evident to those traveling by land or air along the Lardeau River, but they are primarily (60%) associated with pools, which only comprise 18% the wetted area of the river on average. This is the reason the tally of jams as a maximum of 10 pieces provides a more realistic appraisal of the amount of large wood within hydraulic units of the river. Logjams of all sizes play a major role in the fluvial geomorphology and fish habitat of the Lardeau River, but caution is needed in extending their biological role beyond their local catchments (Photo 1).

Figure 6. Total Functional large wood, and functional large wood > 30 cm and > 40 cm diameter in the Lardeau River in 2002.

Photo 1. A typical logjam dominated by smaller large woody debris in mid-Reach 3 of the Lardeau River in 2002. Note evidence of bank erosion and probable channel widening at the riparian young forest interface with the Lardeau River.

These results indicate that total large wood is relatively abundant in the Lardeau River. Yet, at a functional level, habitat managers should be cognizant of a trend towards smaller wood, with less large wood, which drives much of the Lardeau River's geomorphology and its salmonid habitat. Past wood recruitment was dominated by old-growth of mature cedar (Photo 2) and cottonwood, with the former dominant (key logs) in most of the larger log jams of the river today. Existing moderate levels of smaller wood in most reaches appears to reflect long-term shifts within the primary sources of large wood to the Lardeau River, which is likely to affect the quantity of prime salmonid habitats in the future.

Riparian Structure and Functions

Large wood in the Lardeau River is contributed from three primary sources as: (1) driftwood from Trout Lake, (2) tributary transport and (3) riparian areas of the river, the latter via both windfall and erosion processes. Natural or logging-induced landslide events from main valley hill slopes are very sparse and do not appear to contribute large wood sources to the river. Of the seven tributaries, only Mobbs Creek is noted for periodical debris flow events, and the bridge at Gerrard has not historically accumulated jams of large wood consisting of whole trees. Thus, it is the riparian areas of the large Lardeau floodplain that contribute the majority of the large wood to the river system. In large rivers, such as the Lardeau, lateral movement of meander bends within the floodplain is probably the greatest contributor of large wood in the system, and historically resulted in the numerous jams which at their core are largely of old-growth origin (Photo 2).

Photo 2. Old-growth red cedar stands were prevalent throughout much of the Lardeau floodplain, which is still evident by the stumps on riparian banks (Photo 3) and an abundance of cedar logs and rootwads in the logs jams of the river.

Riparian forests in all reaches are not dominated by mature forests because of historical logging or clearing to the riverbanks (Table 5; Photo 3). Thus, there was virtually no mature forest on both banks in the sampled sections of all reaches. On one of two streambanks, mature forest only accounted for 6.4% of riparian tree cover on average, which was largely in Reach 4. Young forest and pole sapling were the most prevalent forest types, and because pole sapling are mainly a succession species on floodplain bars, young forest was the predominant forest cover of riparian streambank areas. Young forests are trees of any species up to about 80 years of age, and in the Lardeau riparian zone appear to be mainly in the 25-50 years of age, although no age assessments of riparian trees were made.

Table 5. Riparian conditions of the Lardeau River in 2002, including % maturity of riparian forest (MF = mature forest, YF = young forest, PS = pole sapling).

Reach	Mature Forest	Young Forest	Pole Sapling	PS/MF MF/PS	YF/MF MF/YF	YF/PS PS/YF	Road/PS
1	0	42.9	14.2	4.7	4.7	19	14.2
2	0	16.6	50	8.3	0	16.6	8.3
3	0	36.4	63.6	0	0	0	0
4	0	14.3	0	28.6	14.3	42.9	0
5	0	22.2	0	0	0	77.7	0
6	0	0	50	0	0	40	10
Mean	0	22.1	29.6	6.9	3.2	32.7	5.4

As a common disturbance indicator, bank erosion was evident in numerous geomorphic settings including straight channels and the outside of meander bends, particularly in Reach 2 and 3 (Photos 3, 4). How much of the bank erosion process has accelerated by a lack of a mature forest is uncertain? However, the expansive bankfull channel width in Reach 2 (93 m) and Reach 3 (107 m), which was 3-fold that of the late summer-fall wetted width and about 1.7-2-fold that of other reaches, suggests widening as result of past streambank logging is in progress as described and predicted by Millar (2000). A detailed analysis of historical air photos would be needed to confirm if the channel of the Lardeau River is widening in response to past logging, as root masses decay and small 2nd growth riparian trees regenerate over time.

Photo 3. Riparian second growth showing evidence of old-growth stumps from historical riverbank logging.

Photo 4. Typical riverbank erosion at a Reach 2 meander bend in Lardeau River

Pool Habitat Features and Cover

Primary pool spacing of six channel widths per pool is the average spacing found in nature (5-7 widths; Newbury and Gaboury 1997). Only Reaches 5 (10) and 6 (12) were higher but within the range to be expected because the distribution in nature is wide, ranging from 3-20 in pristine streams. The fish habitat assessment procedure also incorporates secondary pools or "pocket" pools (> 20 m^2) within other hydraulic units. Such pools were sparse, particularly in Reaches 4 and 5 (Table 6). Based on the procedural diagnostics, Reaches 2, 3 and 6 rated "good", but Reaches 1, 4, and 5 rated as only "fair". On average percent pool area (primary and secondary) at 19% rated as "poor", and only one reach (2) was within the "fair" category at > 40%. However, this is not a result of low frequency of primary pools, which repeated on average every six widths, but rather due to a low frequency of sub-pools or pocket pools. In a river the size of the Lardeau, one would not expect 55% pool LWD as in small streams and thus, 40-55% is conservative for rivers. Regardless, the frequency of "pocket" pools is relatively low in the Lardeau for a river (Table 6). These pools are typically caused by obstacles along riverbanks, including rootwads and fallen trees but there is virtually no large wood along the Lardeau to wind-throw or fall via decay into the wetted channel. This "early warning" indicator was particularly evident in Reach 4 where such pools were sparse.

Fish habitat cover rated "fair" in most categories. Cover in pools was high, particularly in Reach 1 (Fig. 7). Depth, turbulence, boulders and LWD comprise pool cover for juvenile rainbow trout and other species. Thus, deep pools of a large stream typically have high cover ratings unless river flows are at a low percentage of mean annual flow. Cover in glides was moderately low on average, and in riffles was < 5% in Reach 1, 2, 3 and 5. From the fish habitat diagnostics, boulder cover in riffles rated as "poor", but this was largely as a result of the natural lack of boulders in the Lardeau River, which were only significant in Reach 4 (Table 6; 10%), and relatively low compared to most steelhead rivers (e.g., Chilliwack River). In filling of boulders as a disturbance indicator was not rated, but did not appear excessive in Reach 4 where boulders were most abundant.

The percent LWD in pools averaged 10% and ranged from 6 to 19 and thus all reaches were rated as "fair". Total cover or overhead cover averaged 15 % (Fig. 8), and ranged from 10 % to 22 %, and rated "fair" except in Reach 1 which rated "good" according to diagnostics tabled in Johnston and Slaney (1996). The primary cover feature in the

Lardeau River was LWD, and averaged 56% in percent composition of cover types, with depth second at 20% and bank vegetation third at 13%, followed by boulders at 8%.

Secondary or pocket pools are mainly generated by mature to old-growth riparian forests with substantive root masses. Their scarcity is therefore another disturbance indicator that should be examined in more detail by comparisons to river segments with mature riparian forests. Large wood is crucial for cover in the river as well as its geomorphological role in scouring deeper pool and run habitats required by large juvenile trout as well as other species including mountain whitefish and bull trout.

Table 6. Pool characteristics in the Lardeau River by Reach in 2002.

	Number of				Channel	Mean
Reach	**Primary Pools**	**Chan. Widths / Primary Pool**	**Sub-Pools**	**Total Pools**	**Widths per Pool**	**% Pool by Area**
1	8	4.5	3	11	3.3	28.5
2	6	2.7	10	16	1	41.7
3	4	3	7	11	1.1	11.1
4	3	5.5	3	6	2.8	10.1
5	2	9.8	4	6	3.3	10.2
6	2	12	17	19	1.3	14.3
Total	25		44			
Mean		6		12	2.1	19.3

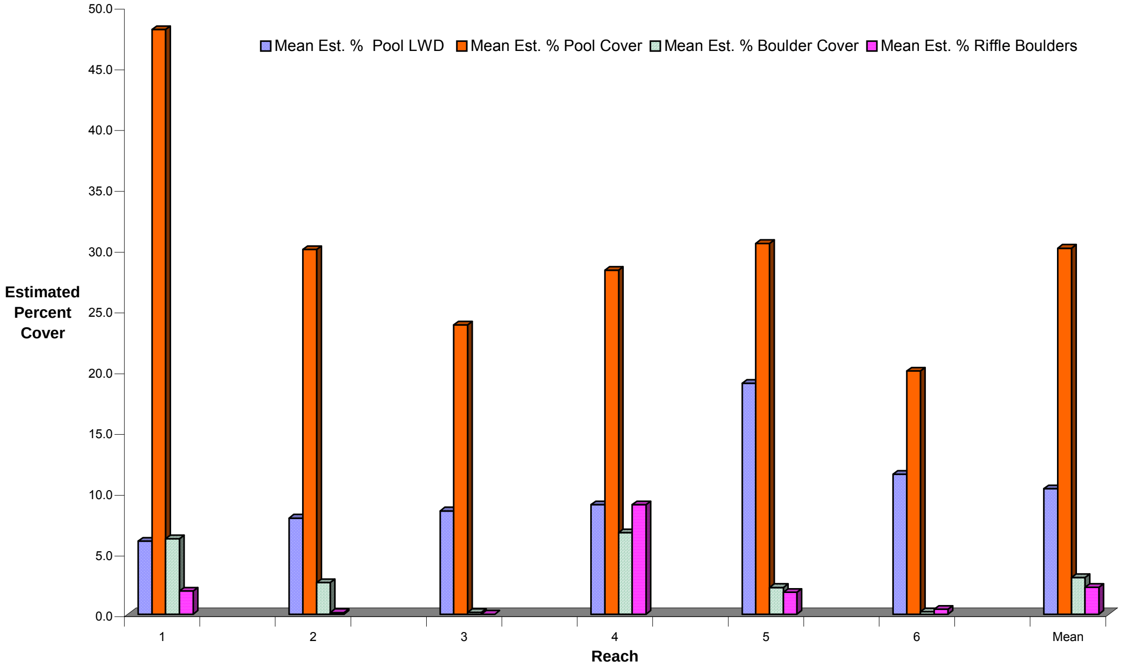

Figure 7. Estimated percent fish habitat cover in riffles, glides and pools, and percent LWD of pools area in the Lardeau River in 2002.

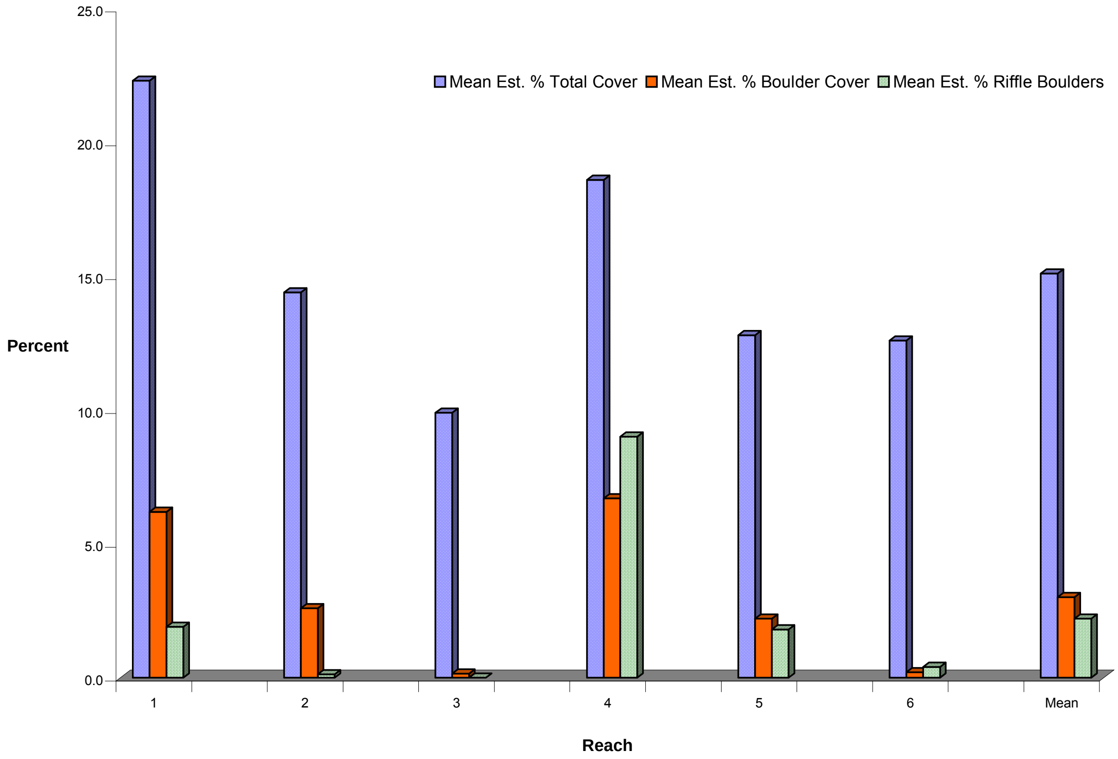

Figure 8. Total cover, total boulder cover, and riffle boulder cover in the Lardeau River in early fall, 2002.

Side-Channel Habitat and Logjams of the Lardeau River

Side channels are common at the Lardeau River within each reach and provide both fry and parr habitat, particularly the former. Twelve side channels were surveyed, ranging from one in Reach 6 and 4, two in Reach 1, 2, and 3, and four in Reach 5 (e.g., Photo 5). Average bankfull and wetted width in early fall was 26 m and 6.2 m. Total (expanded) wetted area was 141,319 m^2 (Table 7), and LWD was also prevalent in side-channels because most originated at logjams. Total LWD and functional LWD per channel width rated “high” on average; percent cover was significant or 12% on average (PSLaney Aquatic Science Ltd. 2003). Useable velocities and depths favoured fry rearing over parr in the Lardeau side-channels, and mean estimated useable habitat varied among reaches fry, parr as follows: 45%, 9.5% (R1), 10.5%, 4.2% (R2), 3.6%, 2.2% (R3), 10%, 0% (R4), 10%, 2% (R5) and 8%, 13.2 (R6). On average in September, side-channel had 14.5% fry habitat and 5.2% parr habitat, a 2.8-fold difference that was not significant (P > 0.05) owing to a high fry variance.

Disturbance Trend Indicators

As a disturbance indicator, a distressing trend on the river is that the second growth riparian forest is still highly dominated by a "young forest" stage of re-growth. Other than sporadic old-growth stumps, there appears to be little natural recruitment of > 30 cm diameter large wood from erosion and wind-throw processes, except in lower reaches. This is evident in the large wood accumulations in the river channel where wood < 30 cm comprised 52% of functional large wood on average and was 62% in Reach 2, as is evident in Photo 1. Further, when large functional wood > 30 cm is used as the diagnostic, large wood is only within or near the "fair" rating in three of six reaches.

Table 7. Estimated length (m) and area (m^2) of side-channel habitat in six Reaches of the Lardeau River in early fall 2002 (expanded).

Reach	Expansion Factor	Expanded Length m	Mean Wetted Width m	Expanded Area m2	Expanded Useable Area Fry Habitat m2	Useable Area Parr Habitat m2
1	3.83	1,471	4.1	6,030	2,713	573
2	4.54	2,252	7.8	17,564	1,844	738
3	5.51	3,978	8.3	33,019	1,189	726
4	6.93	5,045	6.6	33,297	3,330	0
5	5.94	2,418	2.4	5,802	580	116
6	5.52	2,534	18	45,606	3,648	6,020
	Total or Mean	17,697	7.9	141,319	13,305	8,173

Given the young age of riparian forests, LWD is more likely to decrease over time via decay of > 30 cm wood.

From a habitat perspective the key factor that has "saved" the river so far, with its renowned Gerrard rainbow, is the predominance of Western Red Cedar among the existing accumulations of large wood. The decay rate of large wood in streams on average is 3% (Bisson et al. 1992), but cedar is about half this rate. Also, it is fortunate that large diameter logs decay about half the rate of small logs. Consequently, residual mature to old-growth cedars of > 30 cm basal diameter in the channel have delayed potential unraveling and loss of crucial habitat features that has occurred on other streams (e.g., Millar 2000), although widening appears in progress in Reaches 2 and 3. In these reaches, bankfull width (93 and 107 m) was 58% and 80% greater than the mean width (59 m) of the other four reaches ($P<0.05$). Yet, the existing second growth forest is slow to mature, and a major uncertainty is whether the in-channel large wood will have diminished before the recruitment of large-sized second growth recovers.

Photo 5. Log jam-controlled side-channels provide prime fry and some parr habitat.

It is also important to note that based on wood removal experiments in streams, the incidence of large wood in wetted channels is also important for driving fish food chains; aquatic insect abundance decreased 4-fold after woody debris removal from a stream channel (from an October 2000 symposium in Corvallis, Oregon).

In the overall assessment, pool ratings trended towards "fair" in half of the reaches. Low frequency of secondary or "pocket" pools, typically generated by rootwad obstacles along riverbanks, is low due to virtually no large LWD to wind-throw or fall via decay into the wetted channel. Mature trees that wind-throw often hang up on banks and create habitat where they project into the wetted channel or where their rootwads erode into the channel. This "early warning" indicator was particularly evident in Reach 4 where such pools were almost lacking except in one riffle. The latter was probably caused by historical attempts at log drives in this reach because there was evidence of old cut-off cedars at 45^o that extended over the river (Alexander 1998). Reach 4 does have some mature cedar, which may have been too small at the time of early days of logging described by Alexander (1998). Currently, it appears to be at an age when LWD recruitment is at a minimum (about 80-100 years) before re-supply initiates at about 100 years of age.

In Reach 4, almost all (89%) of the wetted area was comprised of riffle. There, and to a lesser degree in Reach 5, large wood restoration should be pursued incrementally to ensure secondary pools are recovered, using a similar template as shown in the report cover plate, which is very similar to the triangular or A-log design described in Slaney et al. (1997). This formation was demonstrated to have stability and high functionality in several rivers where it was tested (D'Aoust and Millar 1999). A more recent design ensures bank protection and captures driftwood, and it is strikingly similar to the natural template in illustrated in the cover plate. Accordingly, it is generally accepted today that restoration should focus on restoring natural processes (Roni et al. 2002).

Large wood loss in nature occurs at 10% a decade, declining to 5% a decade after about 50 years at this latitude in the Interior "wet belt" (Koski 1992). Unfortunately, re-supply of large wood does not initiate until about 100 years and does not fully recruit LWD until after 150 years. The cycle may be extended in the hemlock-cedar biogeoclimatic zone of the Lardeau Valley where cedar is a dominant climax vegetation type on floodplains. If Reach 4 is an example of what the habitat conditions in the river might be in the next 50 years, fish habitat conditions are going to deteriorate before improving. This is despite the fact that the functional condition (using LWD as the primary "early warning" indicator of the six reaches) at this time interval is rated as 50% "fair" and 50% "good", with some channel widening evident in at least two reaches.

Preliminary Parr Production Modeling

Fry Versus Parr Habitat Limitations

Estimated percent useable fry habitat in the mainstem was lower than useable parr habitat or 2% versus 8%, a 4-fold difference (Table 8; $P<0.05$). Total sampled parr habitat in the mainstem was 25,617 m^2 compared to 8,406 m^2 or a 3-fold difference (Table 9; $P<0.05$). When expanded by individual reaches (with different expansions factor) total fry and parr habitat was 41,938 m^2 and 130,390 m^2, respectively, and thus, estimated useable fry area was 32.2 % of parr area or a 3.1-fold difference (data from Tables 7,8 by reach). However, in sharp contrast were the habitat estimates in the side-channels. Fry habitat comprised 14.5% of side channels and parr habitat comprised 5.2% (PSlaney Aquatic Science Ltd. 2003), but this was not statistically significant owing to a high variance ($P>0.05$). Total area of fry habitat in side-channels was only about twice that of parr because of a wide extended side-channel in Reach 6 which dominated the expanded area (Table 7). Combining mainstem and side-channel areas, estimated useable fry and parr habitat (expanded) was 55,243 m^2 and 338,563 m^2, respectively, a 2.5-fold difference.

These estimates are considered preliminary and should be used cautiously at this stage because: (1) velocities and depths were estimated from surface conditions and not measured; (2) expansion factors were large or 5 times on average; (3) small groundwater snyes associated with bars were not included; and, (4) small groundwater feeder streams such as that located at 45 km were not included. These small feeder streams and the groundwater sites at the downstream end of some meander bars were observed to be utilized by rainbow trout fry and they may be significant on a whole river scale, perhaps adding > 10 % to the area of fry habitat. On the other hand, fry habitat at higher flows in mid- to late July after fry have emerged and dispersed (Irvine 1978a) may be less abundant than in September, and this needs to be confirmed.

Based on the above, estimated useable fry habitat equated to 40% of useable parr habitat. Regardless, the amount of fry habitat in September in the Lardeau River should not be assumed to limit parr production capability. This is because the summer territorial area of fry weighing 0.2-0.5 g is only 5-10% of that of yearling parr (5.0-10 g) since territory size is directly proportional to weight (Allen 1969, Slaney and Northcote 1974). Theoretically, if fry and parr were at about the same densities in the river, and in-river survival was high, there could be at least 10 times the amount of parr habitat before fry habitat limits migrant parr production even though there was an estimated 2.5 times more parr habitat in the Lardeau River. However, differential survival rates of fry and parr must also be taken into account for any valid comparison.

Fry survival is density dependent as described by Irvine (1978b) and Ward and Slaney (1993). At Keogh River, survival of early fry (1 month post emergence) averaged 12% and ranges from about 5% to 25%. This range largely reflects density dependent survival (Ward and Slaney 1993), and therefore 20% survival of Lardeau rainbow fry at low densities (0.2-3 fry/m^2) is a reasonable assumption. Age 1+ to smolt survival averaged 40% at Keogh River (Ward and Slaney 1993). However, Irving (1978b) suggested survival of fall fry to yearling parr was 67%, and thus 50% survival of fall fry to parr is a realistic assumption if age 2 migrant parr are included. Under such a scenario Lardeau rainbow fry would initially only need to be twice as abundant as parr per m^2 of useable habitat, if the amount of useable habitats was the same.

Fry sampling by Redfish Consulting Ltd. (2002) indicated low densities (0.12/m^2). If adjusted for useable fry habitat, these densities should be close to 0.3/m^2 similar to those reported by Irvine (1978b). Irvine's total fall fry estimates were based on fry densities (0.33/m^2) and useable habitat of 1.5 m strips along the margins of the river. Thus, at this fry density and a parr density of 0.15/m^2 (≈50% of fry) in useable habitat at capacity (given its moderately high nutrient-based productivity) there should be equal areas of fry and parr habitats. However, the estimated parr habitat was twice that of fry habitat suggesting that there should have been twice the fry densities than what were actually estimated in 2002, i.e., 0.25/ m^2 per sampled area or 0.6/ m^2 per useable fry area to attain parr capacity. As previously mentioned, it is most likely that useable fry habitat has been underestimated.

Table 8. Mean wetted lengths, widths, and sampled areas, and estimated percent useable fry and parr habitat, plus unexpanded (sampled) useable parr habitat area by Reach in the Lardeau River in 2002

Reach	Hab. Unit	Length m	Mean Width m	Area m^2	Estimated % Useable Fry Habitat	Estimated % Useable Parr Habitat	Area m^2 Fry Habitat	Area m^2 Parr Habitat
Reach 1								
Total/Mean		76.7	36.4	55,587.0	4.0	14.5	2,422.4	6,754.8
Riffle		72.9	42.9	21,452.0	4.3	2.6	1,006.8	576.2
Glide		97.2	37.4	18,295.0	3.8	4.8	865.7	862.4
Pool		67.6	29.3	15,840.0	3.9	32.5	549.9	5,316.1
Reach 2								
Total/Mean		74.2	30.4	59,002.0	2.7	6.2	1,719.0	4,571.5
Riffle		108.9	33.7	29,617.0	4.9	2.9	1,266.8	866.5
Glide		63.0	35.8	3,193.0	2.9	9.2	95.8	319.3
Pool		46.6	23.6	21,654.0	0.4	7.5	188.53	2,970.8
Run		46.5	31.5	2,940.0	0.3	12.5	8.4	399.0
Flat		47.0	34.0	1,598.0	10.0	1.0	159.8	16.0
Reach 3								
Total/Mean		98.8	31.5	45,370.0	0.8	3.8	619.5	1,456.9
Riffle		81.6	32.8	13,048.0	0.8	2.2	97.2	385.3
Glide		118.3	35.0	12,916.0	0.7	2.7	74.2	485.7
Pool		77.0	22.0	1,694.0	0.0	20.0	0.0	338.8
Run		46.0	24.0	3,330.0	0.5	3.0	16.7	103.4
Flat		306.0	47.0	14,382.0	3.0	1.0	431.5	143.8
Reach 4								
Total/Mean		145.9	42.1	46,160.0	1.4	4.7	742.1	2,099.8
Riffle		221.3	46.5	41,488.0	2.0	4.3	721.4	854.1
Pool		53.5	38.0	3,715.0	0.5	6.0	16.0	207.3
Run		29.0	33.0	957.0	0.5	4.0	4.8	8.3
Reach 5								
Total/Mean		132.3	45.7	55,453.0	1.7	8.8	1,323.1	4,590.0
Riffle		129.6	49.2	32,879.0	1.8	2.8	725.3	908.0
Glide		192.0	47.5	16,931.0	2.5	12.5	561.2	2,805.9
Pool		60.0	33.0	1,980.0	0.0	35.0	0.0	693.0
Run		99.0	37.0	3,663.0	1.0	5.0	36.6	183.2
Reach 6								
Total/Mean		158.6	42.9	70,841.0	2.7	8.9	1,580.3	6,144.2
Riffle		141.4	45.4	34,409.0	1.9	10.3	669.1	2,537.7
Glide		202.0	42.0	26,313.0	1.3	14.6	301.8	2,160.8
Pool		179.0	35.0	6,265.0	3.0	8.5	31.3	1,253.0
Run		94.0	41.0	3,854.0			578.1	192.7

Table 9. River (grand) mean wetted lengths, widths, and areas, and estimated percent useable fry and parr habitat, plus useable parr habitat area in the Lardeau River in late September 2002 (all reaches averaged - unexpanded).

Reach	Length m	Mean Width m	Area m2	Estimated Useable Fry Habitat	Estimated % Useable Parr Habitat	Area m^2 Fry Habitat	Area m^2 Parr Habitat
Lardeau Gr. Totals							
Total/Mean	114	38	332,413	2	8	8,406	25,617
G.T.Riffle	126	42	172,893	3	4	4,486	7,128
G.T. Glide	135	40	77,648	2	9	2,104	7,416
G.T. Pool	81	30	51,148	1	18	749	10,412
G.T.Run	63	33	14,744	0	5	645	916
G.T. Flat	177	41	15,980	7	1	591	160

Estimated Parr Yield from Lardeau River

Based on the adjusted steelhead smolt model, estimated parr yield from the Lardeau River was 46,275 parr (data in Tables 10, 11). Most of these would migrate to the river in mid- to late spring after insects peak in abundance in May (Slaney and Northcote 1974). Similar to steelhead, and as documented elsewhere, a smaller portion would remain in the river and migrate as age 2, and perhaps a few at age 3. The total parr estimate is 30 % less than that of Irvine (1978b).

Of the total parr production from the mainstem (under existing habitat conditions that are gradually shifting as a result of past logging to river banks), 33,946 m^2 or 73.4 % are produced in riffles, 6,888 m^2 or 14.9 % from pools, 4,256 m^2 or 9.2 % from glides (or flat-runs), 1,151 m^2 or 2.5 % from runs and 35 m^2 or 0.08 % from flats. Comparatively, from the unexpanded total of wetted areas, the Lardeau River mainstem is comprised of 52 % riffle, 26 % glide, 14 % pool, 4 % run, and 5 % flat. The ratio of these two data sets (% parr yield: % frequency) provides an instructive index of value of these habitat units in the Lardeau River, which in order of estimated parr production was: 1.6, runs; 1.4, riffles, 1.1, pools; 0.35, glides and 0.02 flats (data in Tables 8-11). Clearly, the useable parr habitat of riffles, runs, and pools are the “drivers” of parr production. Parr production currently originates in the riffles and pools (88%) which comprise 66% of the river’s habitat units. To a casual observer viewing the river channel, it is the logjams associated mainly with pools that appear most important for parr production, yet only 15% of predicted parr yield may be from these areas. The gradual loss of LWD in riffles and associated widen discussed earlier is therefore a major concern.

Mean predicted percent parr yield from each Reach was: Reach 1, 14%; Reach 2, 10%; Reach 3, 6%; Reach 4, 41%; Reach 5, 12%; and Reach 6, 16%. Reach 4 was highest largely owing to significant boulders and overhead cover in riffles, followed by Reach 6, which has considerable instream LWD in riffles. Of interest, the two reaches with the most bank erosion, the least boulders in riffles and the most LWD (albeit, largely outside the wetted channel) had the lowest estimated parr production. Further, in 4 of 6 reaches, riffles were the primary source of parr production: Reach 1, 36%; Reach 2, 38%; Reach 3, 65%; Reach 4, 98%; Reach 5, 44%; and Reach 6, 90%. Reach 1 and 2 were exceptions where pools were important in parr production; 54% and 46%, respectively.

Table 10. River mean cover variables, TDS and water temperature adjusted parr numbers (predicted) from the Lardeau River, 2002.

TABLE 10 TO BE INSERTED HERE

Table 11. Grand means or totals of cover variables, predicted parr densities, and adjusted parr numbers (for TDS and water temperature), and expanded parr yield from the mainstem of the Lardeau River in early fall, 2002.

Hab.Unit	Bould. Cover %	Overhd. Cover %	Total Cover %	Parr No./m2	Predic. Parr No.	TDS	Mean Temp.C	Temp. TDS Adj. Parr No.	Expand. Total Parr No.
Lardeau **G.Totals**									
G.T./Mn	3	12	15	0.046	3,741	Tab.10	Tab.10	8,323	46,275
G.Riffle	2	4	6	0.014	2,648			5,684	33,946
G. Glide	2	9	11	0.074	371			804	4,256
G. Pool	4	37	41	0.064	621			1,605	6,888
G.Run	2	11	14	0.110	99			223	1,151
G. Flat	1	1	2	0.017	3			6	35

Modeled Side-channel Production of Parr

Parr production from side-channels also requires adjustment for useable area, but this may be questionable because much of the side channel habitat was clearly not parr habitat due to shallow depth. Many of these areas had flat waters as a result of low side-channel flows, except for two well-flowing side-channels in Reaches 2 and 6. Useable areas were estimated in the modeling exercise using the ratios from the main river channel (Data from Fig. 7) to generate parr estimates (Table 12). Model parr densities utilized were the same as for the mainstem except the average density in mainstem riffles was included with those for other habitat units, to derive an average density for all units (0.047/m^2). Yield was then adjusted for TDS and water temperature. Thus, total parr yield from side-channels was estimated at 767, reflecting their small useable areas (Table 13).

Table 12. Estimated percent useable fry and parr habitat and estimated habitat area per reach in side-channels of the Lardeau River in 2002.

	Est. Mean % Useable Fry Habitat	Est. Mean % Useable Parr Habitat	Area Fry Habitat m^2	Area Parr Habitat m^2
R1	45	9.5	2,714	573
R2	10.5	4.2	1,844	738
R3	3.6	2.2	1,189	726
R4	10	0	3,330	0
R5	10	2	580	116
R6	8	13.2	3,648	6,020
T/M	14.5	5.2	13,305	8,173

Table 13. Model predicted parr yield from side-channels (expanded) of the Lardeau River from estimates of useable areas conducted in 2002.

Parr no./m^2	**Predicted Parr No.**	**TDS**	**Mean Temp. C**	**Temp. & TDS Adjust. Parr Yield**	
0.047	26.9	102	9.2	73.9	R1
0.047	34.7	97.4	8.9	88.2	R2
0.047	34.1	92.8	8.6	80.2	R3
0.047	0.0	88.3	8.3	0.0	R4
0.047	5.5	83.7	8	10.8	R5
0.047	282.9	79.1	7.7	513.9	R6
	384			**767**	**Total**

Duncan River Parr Yield

Predicted parr production capability (adjusted) from Duncan River downstream of the Lardeau confluence was an additional 2,775 parr (Table 14). However, this assumes that: (a) there is sufficient useable underyearling habitat to fill the parr habitat; and (b) that undersized parr, yet too small to migrate to Kootenay Lake, take up residence in the Duncan River, similar to that documented for steelhead parr in the Keogh River (J. A. Burrows, 1994 MSc thesis, UBC). Useable fry and possibly parr habitat in the

Duncan River is compressed substantially by operations of the Duncan Dam, such that high flows at unusual times of the year and probable oligotrohication, combine to reduce and eliminate some viable rearing habitat. Useable habitat in the side channels also shifts with flow releases from Duncan Dam (R. L. & L. 2000).

Table 14. Model predicted parr yield from Duncan River and its side-channels from visual estimates of useable widths conducted in 2002.

Reaches	**Habitat Unit**	**Area m^2**	**Est. Use. % Parr Hab.**	**Est. Useable m^2 Parr Habitat**	**Predicted Parr no./m^2**	**Predicted Parr No.**
1	Mixed	96,100	0.0	0	0	0
2	Mixed	39,100	0	0	0	0
3	RIF	7,750	3	233	0.0143	3.3
3	Run	54,253	5	2,713	0.11	298
3 S.chan.	Rf/Ru/Fl	94,666	5	4,733	0.047	222
3	Log jam/bar	29,618	7	2,073	0.11	228
3	Snye	88,853	0	0	0	0
3	Backwater	1,384	0	0	0	0
4	Riffle	17,690	3	531	0.0143	8
4	Run	17,966	7	1,258	0.11	138
4	Snye	1,576	0	0	0	0
4	Backwater	512	0	0	0	0
5	Riffle	19,240	5	962	0.0143	14
5	Run	77,571	7	5,430	0.11	597
5	Jam/bar	29,013	10	2,901	0.11	319
5 S.chan.	Rf/Ru/Fl	89,177	5	4,459	0.047	210
5	Snye	1,222	0	0	0	0
5	Backwater	1,832	0	0	0	0
S.total						2,038
TDS + AdJusted	**Temp. Total**					**2,775**

Total Lardeau and Lower Duncan River Parr Production

On the basis of the model estimates the predicted parr yield from the mainstem and side channels of the Lardeau River was **47,042**; and from Lardeau and Duncan combined was **49,817**.

Preliminary Parr Model Uncertainties

There are a number of assumptions and uncertainties associated with the model used in this report to estimate Gerrard rainbow trout fry and parr numbers. Improvements to the estimates are anticipated in the near future as additional fieldwork is conducted. Some of the weaknesses of the model used include the following:

1. Potential Rainbow and Steelhead Habitat Differences.

Application of a model from a small coastal river to a large interior river was made possible by adjusting for the percentage of useable river and side-channels. However, some habitat relationships may vary owing to selective pressures related to large piscivores in the river-lake system. For example, parr may avoid open areas of the mainstem among small dense boulders and overhanging vegetation. This may not apply as much to Reach 4 and to some extent Reach 6 where mature trees are recovering well and boulders exist. On the other hand, riffle areas in Reaches 1-3 with frequent (up to 25% of the area) small boulders with little cover at both margins of the river may not be used as much as predicted (Table 10). Aside from Reach 1, boulder substrates in the Lardeau River are small, typically ranging from 30-40 cm in diameter. Yearling and underyearlings steelhead are well documented to inhabit these types of riffle boulders in high densities. In contrast, inland riverine rainbow parr may only use them at the underyearling stage in summer to fall in streams with large numbers of bull trout.

It is most likely that a Lardeau parr production model should be adjusted further to account for variations in habitat use including density of parr as a function of boulders and their size range. Relative densities associated with other cover features should also be refined where possible through snorkel survey. A constraint on applying this technique is that rainbow parr are less observable early in the morning and once water temperatures are <13^{o}C, and are exceptionally difficult to detect at < 10^{o}C. They can be observed at night at lower temperatures as suggested by Hagen et al. (2002), but in LWD and log jams where many parr reside, there are significant safety risks associated with nighttime snorkel observations.

2. Underestimated Useable Habitats.

Velocities were not measured during the 2002 Lardeau River survey, but rather were estimated and judged by consensus by the authors. Depths were measured, but not off the opposite bank. Experience with these measurements in rivers, and use of IFIM Bovee curves that were applied routinely at each habitat unit should have minimized some errors from this source. However, testing of measured versus estimated over a range of flows on the Capilano River indicated that on average useable areas of steelhead fry were underestimated significantly (by up to 2-fold); parr useable areas were similar among the two methods, but sample size was small. Thus, there is a need to measure a sub-sample of depths and velocities and develop a standardized correction factor to apply to model calculations of parr for both rivers.

3. Flow-induced Variation in Useable Habitat.

Useable parr habitat may be compressed in the Lardeau River at high flows in June and early July although it would be at a time when parr would be out-migrating and prior to fry emergence. Flows in April-May should provide useable parr habitat and coincides with when biomass of benthic insect are at their annual maximum. Loon Lake parr migrate out of the creeks and into the lake in mid-to late May as insects decline with their emergence (Slaney and Northcote 1974). Thus, natural flows should provide adequate useable habitat until migration in mid-late May to early June, as at Loon Creek (Slaney and Northcote 1974). Unnatural flows evident in the Duncan River in the late summer-fall would clearly result in compression of fry and parr habitat.

4. Parr Production Per Useable Area.

Useable channel width for steelhead parr in the Keogh River in late spring to early summer is 100% provided there is some form of type of cover, such as boulders. However, in early spring when flows are often 2-fold higher, velocities are excessive in mid-river, which may account for a portion (about 10-20% of parr) passing through the counting fence in the mid-1970s to 1980s (Ward and Slaney 1988). Thus, application of the Keogh steelhead model to another river should be adjusted by the amount of useable parr habitat in mid-spring. Model predicted total parr yield from the Lardeau River and its side-channels was 47,042, and 49,817 including the lower Duncan River. In the Lardeau River some 47,042 parr were estimated from 138,563 (expanded) useable m^2 which equates to a predicted density at parr capacity of 0.34 per m^2 of useable parr habitat. Based on total wetted area of 1,912,347 m^2 (from Table 3 in PSlaney Aquatic Science Ltd. 2003) this equates to a parr density of $0.025/m^2$ of total wetted area. Hence, although the parr estimate is about 30% less than that predicted by Irvine (1978b) who applied a useable width of 1.5 m on each river margin, it appears to be high relative to the estimated useable area.

This issue is probably the greatest weakness that needs refinement by sampling at partial transects to improve accuracy. Refinement of the model should be based on density relationships or averages from the Lardeau River, which may differ from Keogh River. This work should be conducted when the river is at carrying capacity, which may not have been the case in 2002 owing to debris flows onto Gerrard spawning grounds from Mobbs Creek (Redfish Consulting Ltd 2002).

5. Temperature and TDS Data.

The adjusted parr estimates were based on incomplete temperature and TDS data. This shortcoming should be addressed in future sampling work.

Options for Restoration and Off-setting Fish Habitat Losses

Habitat for many fish species including Gerrard rainbow trout, bull trout and kokanee are provided in both the mainstem and throughout many side-channels of the Lardeau River. Bull trout highly utilize the several cool tributaries for spawning, and for rearing to age 1-3+ parr stage, whereas Gerrard rainbow juveniles rely much more heavily on the mainstem and side channels. The mainstem provides 2.5 times as much parr than fry habitat area, and side-channels provide about 1.5 times more fry than parr habitat in late summer to fall and winter. Owing to about 2-fold more parr habitat area in the mainstem, the side-channels become important sources of production of fry and pre-parr juveniles, which either ultimately stay for an additional year in the mainstem, or that migrate as yearlings to Kootenay Lake in mid spring. As in steelhead, their life history likely involves a portion of these early parr migrating out of the side-channels in early spring to occupy prime mainstem parr habitats, the latter gradually vacated by the age 2 year class, and a portion of near-age 1 parr migrate to Kootenay Lake. Thus restoring and improving side-channels, particularly large-scale ones with extensive amounts of lateral LWD should be most beneficial and long-lasting. One of the more productive Lardeau side-channels should be used as an optimum template, and both fry and parr habitat equally targeted, the latter by extensive lateral log jams with preferred velocities and depths, and the former by suitable bar placements with cobble-boulder substrates. Reach 4 and 5 have prime side-channel opportunities where historical log drives impacted channel complexity. Cut-off channels meanders in Reach 1 and fish access at Highway 31 culverts associated with the road should also be a priority for restoration.

Reaches lacking large wood in riffles in the mainstem (Reach 4 and 5) should also be selectively considered for creation of lateral log jams, particularly by using the river geomorphology or natural drift wood supply to maintain such logjams for several decades. Some excess isolated bar wood could be re-deployed, some as latteral jams or debris groins in Reach 3 to reduce the rate of banks erosion, but further meander study from air photos is needed there. The cover plate in this report provides an instructive template for lateral jams. Reach 4 to Reach 5 are good candidates for restoration. To reiterate, these reaches were very likely simplified by historical log drive activities, although small boulders on the margins (including Highway riprap) appear to have offset some large wood losses.

Further investigation of forest manipulation in the riparian zone is warranted since it may be possible to speed up re-establishment of climax riparian conifers (e.g., red cedar) through some thinning, planting and possibly slow-release fertilization.

Long-term habitat changes that are gradually unfolding in the Lardeau River, together with operational impacts from Duncan Dam, place some urgency in incremental restoration of habitat of juvenile Gerrard rainbow. At the same time, monitoring of habitat status should be repeated at minimum10 year intervals to ensure any losses can be offset in sufficient time to preserve one of the most important and valued trout stocks in British Columbia.

SUMMARY

Historical Logging and Railway/Road Impacts

Long-term effects and trends of past logging to riverbanks are summarized in detail in PSlaney Aquatic Science Ltd. (2003). Briefly, some trends were evident that provide an “early warning indicator “on future habitat status:

- Habitat conditions in all reaches of the Lardeau River are highly driven by the existing large wood within the river channel; in turn, the wood’s primary re-supply is from the riparian areas of the floodplain.
- Large wood is abundant in all reaches, with extensive logjam development, and was particularly plentiful in the mid-river reaches (2 and 3) and the lower-river Reach (6). The total channel LWD was rated as “good” based on the assessment procedure using total channel wood.
- Yet, the quality of functional large wood varies greatly between reaches and when wood >30 cm basal diameter is examined, the rating was only “fair” in three reaches (1, 4, 5) of the six, or 50%, which is a concern.
- Several pool and cover characteristics rated more within the “fair” range than “good” range, and large wood played a dominant role over all other cover types.
- Secondary or pocket pools, rather than frequency of primary pools, was the reason for only the “fair” pool rating and a reflection of the dominance of young forest within the riparian zone. Reach 4, in particular was highly dominated by riffle (89%) with very few pocket pools.
- Riparian conditions are highly dominated by young forest, and secondarily pole sapling, the latter largely as a succession stage in meander bends. This condition is expressed in LWD in the river, which is shifting towards smaller pieces (on average 52% < 30 cm basal diameter). This trend is predicted to increase in frequency in the future. As existing larger diameter wood gradually decays and is transported over time, re-supply will be mainly from small diameter wood < 30 cm. Fortunately, in the interim period, the relatively high incidence of Western Red Cedar in the channel, which decays more slowly, is delaying a reduction in crucial habitat features of Gerrard rainbow trout.
- There is significant bank erosion in Reach 2 and to a lesser extent in Reach 3 partly owing to logging to the rivers edge; continued channel widening is probable because these reaches are 60-80% wider than other reaches.
- Side-channels were well developed in all reaches and likely provide considerably more fry habitat than parr habitat, whereas parr habitat was much more abundant than fry habitat in the mainstem.
- In the Duncan River, diverse habitat units exist with significant side-channel development in some reaches, but pools were almost non-existent. The river flowed at high velocities and depths well into the vegetated edge of the riparian zone in mid-summer to fall. Useable underyearling habitat appeared to be sparse, although this was not quantified by hydraulic unit as at the Lardeau River, nor in an earlier study of the Duncan River in 1998-99 (R. L. & L 2000).

Modeled Parr Production per Useable Area

The model predicted total parr yield from the Lardeau River and its side-channels was 47,042, and 49,817 including the lower Duncan River. This is about 30% less than that predicted by Irvine (1978b). However, it was evident that useable fry habitat was probably underestimated and needs refinement by depth and velocity measurements to obtain weighted useable areas. The estimate of useable area and model fish densities need further refinement because the predicted density per area of useable habitat was about twice that expected for an Interior stream of moderately high productivity. Some key points arising from the survey work and model estimates include:

- Reaches with significant riffles generated more estimated parr than expected, particularly from Reach 4 (40 % of mainstem yield).
- Useable fry habitat may be limiting parr capacities and needs to be examined more comprehensively and accurately with depth and velocity sampling.
- Regardless of large counts of functional LWD in Reach 3, less parr were predicted there than from other Reaches, a reflection of low cover in riffles and a relative high portion (32 % of area) of flat (low velocity) habitat.
- The downstream Reach (6) had the lowest boulders, but also had about 2-fold more large wood in riffles and generated high numbers of parr, regardless of lower TDS and temperature compared to upper river reaches.
- Fry habitats dominate parr habitats within side channels, and < 1,000 parr were estimated from side-channels owing to low flow/velocity conditions, regardless of considerable LWD; however, advanced underyearlings probably move out of the side-channels and into mainstem in late winter to early spring to rear for up to two months prior to lakeward migration in May; the side-channels may be used as flood refuges for the smaller underyearlings.
- Irvine (1978b) reported significant underyearling movement (108,000) from the lower Lardeau River; this suggests that such habitat in the lower Duncan River would be important for mid-summer to fall rearing of Gerrard rainbow. The Duncan River probably has very little useable habitat for underyearlings owing to excessive depths and velocities; some side-channels could be important but are prone to variable flows which differ markedly from the natural hydrograph.
- The Duncan river temperature regime is cool in summer for production of rainbow trout, and nutrient concentrations and the N:P ratio suggest oligotrophication which would limit production of all fish species including Gerrard rainbow parr.

RECOMMENDATIONS

Habitat Restoration

- Owing to the high importance of Gerrard rainbow trout, habitat conditions of the Lardeau River should be tracked at intervals of at least every decade owing to the unfavorable trend in large wood supply to the channel.
- Low elevation aerial photos of the entire river and side channels from Trout Lake to Kootenay Lake should be undertaken in 2003.
- A trend towards channel widening in the mid-river reaches should be explored in more detail via historical air photo analysis.
- Given trends and risks in the Lardeau related to past logging of river banks, and current dominance of young riparian forest stands, a greater emphasis on active management of salmonid habitat and its productivity in the Lardeau-Duncan system is advised to ensure habitat impacts and risks are proactively managed.
- Some proactive restoration efforts should proceed incrementally as soon as possible to ensure future losses of habitat features are off-set, particularly in Reach 4 and 5, with re-activation of large wood-filled side-channels as a sound habitat option.
- Consideration should be given to thinning existing young forests, planting and possibly fertilization to speed up the re-establishment of the climax riparian conifer species (i.e. mature red cedars and advanced cottonwoods).
- Large wood should be incorporated in any future Highway riprap work.

Fish and Habitat Assessment

- A comprehensive five year Conservation Plan should be developed that maps out the habitat assessment strategies and restoration activities for this provincially significant river and it's world renown trout population.
- Further refinement of the parr model should be undertaken.
- Parr utilization by each habitat type needs to be assessed and density estimates made by underwater counts, calibrated with a sample of electrofishing estimates.
- Fry density estimates should be repeated in 2003.
- Fry habitat requires further definition through depth and velocity measurements.
- useable fry and parr habitat needs to be examined in the Duncan River mainstem and side-channels using well-replicated transects methods.
- A seasonal assessment of weighted useable fry and parr habitat at replicated partial transects in the Duncan River, using the Lardeau as a control, should be undertaken. Simultaneously, the degree of oligotrohication should be examined further. The highly altered flow regime of the Duncan River appears to have eliminated much of underyearling habitat that would have been historically utilized by Gerrard rainbow trout.
- The habitat/productivity losses associated with the Duncan River may need to be offset as an operational impact associated with Duncan Dam.
- Recordings of temperature and TDS should be conducted at Gerrard, mid-river and Marblehead and lower Duncan River.

REFERENCES

Acara, A. H. 1969MS. Kootenay Lake Rainbow Trout-fry production, fry and spawner survival. B.C. Fish and Wildlife Branch, Misc. Report, 35p.

Allen, K. R. 1969. Limitations on production in salmonid populations in streams. P3-18. *In* T.G. Northcote (*ed.*) Symposium on salmon and trout in streams. H.R. McMillan Lectures in Fisheries. University of British Columbia, B.C.

Alexander, J.W.E.1998. 1998. Lardeau Duncan memories. Gigabytes press, Creston, B.C. 182p

Andrusak, H. and E.A. Parkinson. 1984. Food Habits of Gerrard Stock Rainbow Trout in Kootenay Lake, British Columbia. BC Ministry of Environment, Fish and Wildlife Branch, Fisheries Technical Circular No. 60.

Andrusak, H., and C. Brown. 1987. Kootenay Lake Fisheries Management Plan 1987-89. BC Ministry of Environment, 56 pp.

Andrusak, H. and J. Baxter. 2000. Qualitative Assessment of Gerrard Rainbow Trout Fry in Selected Sites of the Lardeau River in August and September 2000. Redfish Consulting Ltd. Contract report for Fisheries Renewal BC and CKFRP.

Andrusak, H. 2002b. Response of North Arm of Kootenay Lake Kokanee in 2001 to Experimental Fertilization Redfish Consulting Ltd. Contract Report for the Columbia Basin Fish and Wildlife Compensation Program Nelson BC

Ashley, K.I. and P.A. Slaney. 1997. Accelerating recovery of stream, river and pond productivity by low-level nutrient replacement. p 13-1to13-24 *In* P.A. Slaney and D. Zaldokas (ed.) Fish habitat Rehabilitation procedures Province of BC Watershed restoration Technical Circular 9: 360p.

Ashley, Ken, Lisa C. Thompson, David C. Lasenby, Laurie McEachern, Karen E. Smokorowski and Dale Sebastian. 1997. Restoration of an Interior Lake Ecosystem: the Kootenay Lake Fertilization Experiment. Water Qual. Res. J. Canada, 1997 Volume 32 No. 295-323.

Ashley, K., L.C. Thompson, D. Sebastian, D.C. Lasenby, K.E. Smokorowski, and H. Andrusak. 1999. Restoration of Kokanee salmon in Kootenay Lake, a Large Intermontane Lake, by Controlled Seasonal Application of Limiting Nutrients *in:* Murphy, T.P. and M. Munawar. 1999. Aquatic Restoration in Canada Backhuys Publishers, Leiden, 1999.

Bisson, P. A. 1992. T.P. Quinn, G.H. Reeves, and S.V. Gregory. 1992. Best management practices, cumulative effects, and long term trends in fish abundance in the Pacific Northwest river systems. Pages 189-232 *in* R.J. Naiman (ed.) Watershed management: balancing sustainability and environmental change.

Burrows, J.A. 1997. Seaward movements of Keogh River steelhead parr: density-dependent dispersal and premature migration. M.Sc. thesis, Department of Zoology, University of B.C., Vancouver. 58p.

Burrows, J.A. 1993. Size-related survival of resident salmonids from time of lake or river entry: evidence from the literature and scale evaluations. Province of BC Fisheries Management Report No. 100: 58p.

D'Aoust, S. G. and R. G. Millar. 1999. Stability of ballasted woody debris habitat structures. Journal of Hydraulic Engineering 126:810-817.

Cartwright, J.W. 1961. Investigations of the Rainbow Trout of Kootenay Lake, British Columbia with Special Reference to the Lardeau River. BC. Fish and Wildlife Branch, Mngt. Publ. 7, 46p.

Daley, R.J., E.C. Carmack, C.B.J. Gray, C.H. Pharo, S. Jasper, and R.C. Wiegand. 1981. The Effects of Upstream Impoundments on Kootenay Lake, B.C. Canada Inland Waters Directorate, Research Institute, Scientific Series, West Vancouver, British Columbia.

DVH Consulting. 2001. Duncan Dam Status of Knowledge Report. Fisheries Assessment and Planning Study. Contract report for BC Hydro Kootenay Generation Area Kootenay Environment Castlegar BC.

Golder Associates Ltd. 2002. Fish and Aquatic Habitat Resources in the Lower Duncan River, 1998-1999 Investigations. Report prepared for BC Hydro, Castlegar BC. R.L.&L. Report No. 741D; 60p. + 6 app.

Hagen, J., S. Decker and R. Bison 2002. An Evaluation of Nighttime Underwater Surveys and Single-Pass Electrofishing as a Rapid Assessment Technique for Estimating Total Steelhead Parr Standing Stock in the Thompson River System. Contract Report Prepared for the Ministry of Water, Land and Air Protection, Fish and Wildlife Science and Allocation, Kamloops, British Columbia

Hartman, G.F. 1969. Reproductive Biology of the Gerrard Stock Rainbow Trout. *In:* T.G. Northcote (ed.) Symposium on Salmon and trout in streams, H.R. MacMillan Lectures in Fisheries, Univ. of British Columbia: 53-67.

Hartman, G.F. and D.M. Galbraith. 1970. The Reproductive Environment of the Gerrard Stock Rainbow Trout. BC Fish and Wildlife Branch, Mngt. Publ. 15, 51p.

Irvine, James R. 1978a. The Rearing and Feeding Ecology of Juvenile Rainbow Trout from a Large Lake-fed River. MSc Thesis University of British Columbia.

Irvine, James R. 1978b. The Gerrard rainbow trout of Kootenay Lake, British Columbia -a discussion of their life history with management, research and enhancement recommendations. BC Fisheries Management Report No. 72. March, 1978.

Johnston, N.T. and P. A. Slaney. 1996. Fish Habitat Assessment Procedures. Watershed Restoration Technical Circular No. 8 revised April 1996.Watershed Restoration Program, Ministry of Environment, lands and parks and Ministry of Forests, BC Government.

Koning, W.C. and E.R. Keeling. 1997. Salmonid Biostandards for Estimating Production Benefits of Fish Habitat Rehabilitation Techniques *in* Slaney P. A. and D. Zaldokas 1997. Fish Habitat Rehabilitation Procedures Watershed Restoration Technical Circular No. 9. Watershed Restoration Program. Ministry of Environment, Lands and Parks and Ministry of Forests, BC Government.

Koski, K.Y. 1992. Restoring stream habitats affected by logging activities. P 344-397 *in* G.W. Thayer (ed.) Restoring the nation's environment. Maryland Sea Grant Book. College Park, MD.

Larkin, G.A. 1998. Kootenay Lake Phosphorus Loading from the Kootenay and Duncan Rivers. Report prepared for the Columbia Basin Fish and Wildlife Compensation Program, 26 p.

Lirette, M.G., R.S. Hooton and V.A. Lewynsky. 1987. Preliminary steelhead production capability estimates for selected Vancouver Island streams. Province of BC Fisheries Technical Circular No. 74. 23p.

Lister, D.B.and R.J. Finnegan. 1997. Rehabilitating Off-Channel Habitat *in* Slaney P. A. and D. Zaldokas 1997. Fish Habitat Rehabilitation Procedures Watershed Restoration Technical Circular No. 9. Watershed Restoration Program. Ministry of Environment, Lands and Parks and Ministry of Forests, BC Government.

Millar. R. M. 2000. Influence of bank vegetation on alluvial channel patterns. Water Resources Research. 36: 1109-1118

Murphy, M.L. 1995. Forest impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska- requirements for protection and restoration.

US Department of Commerce (NOAA) Coastal Ocean Program. Decision Analysis Series No. 7: 156p.

Northcote, T.G. 1973. Some Impacts of Man on Kootenay Lake and Its Salmonids. Great Lakes Fisheries Commission Tech. Rep. 25.

PSlaney Aquatic Science Ltd. 2003. Lardeau River fish habitat assessment (2002) Integrated with habitat assessments of the Duncan River. Contract report for BC Ministry of Water, Land and Air Protection. 34p.

Redfish Consulting Ltd. 2001. Assessment of Lardeau River rainbow trout rearing habitat restoration opportunities. Contract report written for CKRFP Cranbrook BC and Fisheries Renewal BC.

Redfish Consulting Ltd. 2002a. Kootenay Lake Rainbow Trout Survey Questionnaire Results 2001-2002. Contract report prepared for the Nelson Fisheries Branch of the BC Ministry of Water, Land and Air Protection, Nelson, BC.

Redfish Consulting Ltd. 2002b. Quantitative Assessment of Gerrard Rainbow Trout Fry at established Index Sites on the Lardeau River September 2002. Contract Report for the British Columbia Conservation Foundation.

Redfish Consulting Ltd. 2002c. Construction of a Rainbow Trout Rearing Channel on Tenderfoot Creek. 2001. Contract report prepared for the Columbia Basin Trust and Fisheries Renewal BC.25 p.

Roni, P. T. J. Beechie. R.E. Bilby, F. E. Leonetti, M.M. Pollock and G.R. Pess. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. North American Journal of Fisheries Management 22:1-20.

Schuette-Hames, D., A. Pleuss, L. Bullchild, and S. Hall. 1994. Ambient monitoring program manual. Timber-Fish-Wildlife. Northwest Indian Fisheries Commission. Olympia, Washington.

Sebastian D.C. 1979. Life History Characteristics of Mission Creek Rainbow Trout Based on Scale Analysis. Fisheries Management Report No. 74. Ministry of Environment, BC Government.

Perrin, C.J. and J.S. Korman. 1997. A Phosphorus Budget and Limnological Descriptions in Duncan Reservoir, 1994-95. Report prepared by Limnotek Research and Development Inc., Vancouver, BC for BC Hydro Castlegar, BC 110p.

Slaney, P.A. and T. G. Northcote. 1974. Effects of prey abundance on density and territorial behavior of young rainbow trout (*Salmo gairdneri*) in laboratory stream channels. Journal of Fisheries Research Board of Canada. 31:1201-1209.

Slaney, P.A. 1981MS. A preliminary (revised) steelhead model. Province of BC, Ministry of Environment, Fish and Wildlife Branch Unpublished manuscript report: 5p.

Slaney, P.A. and A.D. Martin. 1997. Planning fish habitat rehabilitation: linking to habitat protection. P 1-1 to 1-23. *in* P.A. Slaney and D. Zaldokas (ed.) Fish habitat Rehabilitation procedures Province of BC Watershed restoration Technical Circular 9: 360p.

Slaney, P.A., R.J. Finnigan and R. M. Millar. 1997. Accelerating the recovery of log-jam habitats: large woody debris-boulder complexes. P9-1 to 9-24 *in* P.A. Slaney and D. Zaldokas (ed.) Fish habitat Rehabilitation procedures. Province of BC Watershed Restoration Technical Circular 9: 360p.

Slaney P.A. and D. Zaldokas. 1997. Fish Habitat Rehabilitation Procedures Watershed Restoration Technical Circular No. 9. Watershed Restoration Program. Ministry of Environment, Lands and Parks and Ministry of Forests, BC Government.

Ward, B.R. and P.A. Slaney. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmon gairdneri*) and the relationship to smolt size. Canadian Journal of Fisheries and Aquatic Sciences 45: 1110-1122.

Ward, B.R. and P.A. Slaney. 1993. Egg-to-smolt survival and fry-to-smolt density dependence of Keogh River steelhead. Pages 209-217 *in* R.J. Gibson (*eds.*) Production of juvenile Atlantic salmon, *Salmo salar*, in natural waters. Canadian Special Publication Fisheries and Aquatic Sciences 118.

Ward, B.R. and P.A. Slaney, A.R. Facchin, and R.W. Land. 1990. Size-biased survival in steelhead trout: back calculated lengths from adults' scales compared to migrating smolts at the Keogh River. Canadian Journal of Fisheries and Aquatic Science 46: 1853-1858.

Wright, M.E., K.I. Ashley, R. Lindsay, R.J. Hammond, F.R. Pick, L.M. Ley, P.B. Hamilton, D.C. Lasenby, L.J. McEachern, M. Duffy, J.D. Whall, L.C. Thompson, D. Miller, L. Vidmanic, D. Sebastian, G. Scholten, M. Young. 2002. Kootenay Lake Fertilization Year 7 (1998/1999) Report. Fisheries Project Report No. RD 98 2002. Ministry of Water, Land and Air Protection, Province of British Columbia.