The Watershed Restoration Program of British Columbia: Accelerating Natural Recovery Processes

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Until recently, in British Columbia, there was no mechanism to ensure the rehabilitation of resource values adversely impacted by logging-induced landslides, erosion from logging roads, and harvesting of mature riparian trees to the streambank. In 1994, the Watershed Restoration Program was initiated under the province's Forest Renewal Plan to provide an opportunity for diverse stakeholder partnerships to accelerate the recovery of watersheds impacted by logging practices of the past. Several decades of research on watershed processes, limitations to salmonid production in streams and rehabilitation techniques, combined with provincial training initiatives, provide the technical basis for application of a set of integrated restorative measures linked to the new Forest Practices Code. As first priority, the conditions of roads, slopes, gullies, riparian areas, stream channels and fish habitat are assessed. Roads are storm proofed by either reestablishing natural drainage patterns or by deactivation. Hillslope scars are revegetated with grasses, shrubs and trees to control erosion, thus increasing fish stock productivity, while also improving water quality, forest regeneration and biodiversity. Riparian silvicultural treatments eventually (one to two centuries) restore recruitment of large coniferous woody debris to stream channels and restabilize streambanks. Large wood, boulder clusters and other structural elements that emulate nature are installed in stable stream channels to restore summer habitat and critical overwintering refuges in streams, thus rehabilitating and maintaining fish habitat until logged riparian areas naturally supply mature windfalls. Restoring of fish access and replenishing of nutrients for the food chain are also provided where assessed as beneficial to the functional recovery process. Rehabilitation of off-channel fish habitat, including creation of channel-pond complexes, is one of the primary techniques to offset habitat degradation in hydrologically unstable or non-functional stream channels within logged floodplains. The program provides an opportunity for innovation and evaluation, as well as a challenge to cost-effectively implement rehabilitation on a sufficient scale to accelerate the recovery of watershed processes to the benefit of fisheries, aquatic and forest resource values in British Columbia's forested watersheds.

Key words: watershed restoration, British Columbia, accelerating recovery

Introduction

It is widely recognized that past land management practices have permitted the degradation of forest lands, water quality and, especially,
fish habitat in western Canada and the northwestern United States (Slaney et al. 1977; Hartman et al. 1987; Koski 1992; Murphy 1995). In most instances, there were no mechanisms in place to ensure rehabilitation of degraded or threatened aquatic resources in forested watersheds in British Columbia. Although it is becoming more accepted that habitat protection measures, such as riparian buffer zones, are more cost-effective than habitat rehabilitation (Koski 1992), a large province-wide legacy of impacted hillslopes and streams in British Columbia necessitates a long-term initiative to rehabilitate impacted areas, where feasible, to environmental standards consistent with the new Forest Practices Code of British Columbia, and thereby accelerate natural recovery processes in our forested watersheds. It is also evident that the effectiveness of new forest practices regulations and restoration activities are codependent, because of interconnections between biological and physical processes within logging-impacted watersheds.

The Watershed Restoration Program is a provincial initiative under the Forest Renewal Plan, funded through a crown corporation (Forest Renewal BC), which was founded in April 1994. It is a strategy to implement a program of rehabilitative and preventative measures to (1) restore, protect and maintain fisheries, aquatic and forest resources adversely impacted by past logging practices, which would otherwise require several decades to recover naturally; (2) provide community-based employment, training and stewardship opportunities throughout the province; and (3) provide a mechanism to bridge historical forest harvesting practices and the new standards established by the Forest Practices Code (FPC), diversifying jobs in the forest sector.

The Ministry of Environment, Lands and Parks, in partnership with the Ministry of Forests, manages the program. Other agencies, including the federal Department of Fisheries and Oceans, are also involved. The program is largely "proponent driven" by the forest industry, First Nations, conservation and community groups, and government agencies, typically in partnerships of stakeholders who have vested interests in rehabilitating resource values, targeting on small- to moderate-sized watersheds. Funding for the Forest Renewal Plan was made available by an increase in "stumpage fees"; in recognition that there was a compelling need for reinvestment in the resource values of our provincial forests as well as in the stability of logging-dependent communities. Through Forest Renewal BC, the Watershed Restoration Program also provides the infrastructure to train and reemploy forest workers to restore natural resource values, fostering community-based stewardship of local resources.

To achieve substantial resource benefits, an integrated watershed approach is the fundamental principle of the program, in recognition of the interconnections between physical and biological processes within impacted watersheds, where streams and riparian zones are either functioning at risk or have become non-functional. Projects are developed cooperatively and are implemented by stakeholders and resource management agencies,
using a sequence of condition assessments of watershed components, followed by prescriptions and restoration or rehabilitation procedures. A provincially coordinated evaluation component is designed to monitor project effectiveness and provide an adaptive feedback loop to ensure techniques are improved and innovations are captured.

**Historical Impacts of Logging on Aquatic Resources**

Logging activities potentially alter all the primary environmental components that affect the productive capability of fish habitat as well as the food chains upon which fish depend. Logging impacts have been difficult to document because of the large natural variability associated with natural stream systems and multiple activities affecting watersheds, including overfishing (Larkin 1975). Case studies, such as the Alsea watershed study (Hall et al. 1987) and the Carnation Creek study (Hartman et al. 1987) have assisted in the understanding of the functioning of stream ecosystems. Shorter-term investigation, including the Slim Creek study in the interior of British Columbia (Slaney et al. 1977a, 1977b), the Clearwater River study on the Olympic Peninsula (Cederholm et al. 1980), comparisons of streamside logging practices in southeast Alaska (Murphy et al. 1986) and the Fish-Forestry Interaction Program on the Queen Charlotte Islands (Tripp and Poulin 1986) have also added to our knowledge of how logging activities affect fish habitat. These and related hydrologic studies have made predictions of the effects of logging on fish production more reliable, albeit incomplete. Other examples, more striking, but less well documented, have also demonstrated that impacts can be severe; e.g., substantial losses (80 to 90%) of important stocks of summer-run steelhead and coho salmon at Deer Creek, in northwest Washington (Kraemer 1994; Doyle et al. 1995). Estuarine back-channels and eel grass areas have also been historically impacted by accumulations of organics associated with marine log sorting. Any benefits of logging, such as improved growth rates of juveniles in cool salmonid rearing streams (Slaney et al. 1977; Holtby 1988), can be offset by cumulative impacts (Murphy et al. 1986; Cederholm et al. 1980).

There are several primary changes that are evident as a result of forest harvesting to the stream bank, which was the common practice in much of British Columbia until the introduction of the Coastal Fisheries-Forestry Guidelines in 1988, superseded by the Forest Practices Code in 1995. There are alterations in solar radiation, water temperature, forest canopy and streambank vegetation, streambank stability, suspended solids, fine woody debris, coarse woody debris, channel morphology, substrate sediments, streamed stability, nutrient supply, and stream flows. Some effects are transient or fluctuate (nutrients can increase then decrease), some recover in decades (stream temperature) and some require over a century (large woody debris from mature or old-growth windfalls) (Meehan 1991). Negative changes are diverse and interactive,
but there is little argument that the more restrictive logging practices of the Forest Practices Code are necessary to protect what is remaining in watersheds still dominated by old-growth, as well as those watersheds that will be logged in the near future as second growth forests.

Landslides and increased peak flows that impact water quality, fish habitat and forest sites have become more evident, especially on steeper slopes in the coastal regions. "Torrenting" of debris-loaded gullies on the coastal regions has been well documented (Cederholm et.al 1980; Hogan 1986). Moderate rates (<25%) of deforestation are known to increase peak stream flows, especially as a result of rain-on-snow events (Harr and Fredriksen 1979). A recent analysis of a 34-year record from three 60- to 101-ha watersheds in the H.G. Andrews Experimental Forest in western Oregon indicated that both 100% clearcutting and 25% clearcutting with roads may increase peaking discharges by more than 50% in the first 5 years, and by more than 25% as long as 25 years after treatment (Jones and Grant in press).

These two processes cause an increase in sediment transport from hillslopes and stream banks, with bedload sediments moving through less stable channels of unconfined, and frequently logged, floodplains. The resultant widening of mainstem channels, infilling of coarser substrates and blocking of side-channels has caused declines in salmon and steelhead stocks, such as that documented at the San Juan River on southern Vancouver Island, where 428 landslides were recorded in logged terrain (Northwest Hydraulic Consultants 1994). Also, 495 landslides have been documented in the Gordon River watershed on southern Vancouver Island, mainly caused by overloading fill-slopes of logging roads (Ministry of Forests, unpublished data, 1994). Similarly, failures of 20-year-old logging roads above a gully on Jones Creek, in south coastal British Columbia, have eliminated a spawning channel utilized by pink and chum salmon, and have caused chronic sedimentation of fish habitat in the stream since 1993. Because both spawning and overwintering substrates are frequently degraded (Scrivener and Brown 1993), the productivity of fish stocks declines, increasing the risk of overharvest of weakened stocks in mixed stock fisheries (Slaney 1980). Although the use of coastal fisheries-forestry guidelines since 1988 have improved protection of fish habitat, slope failures and debris flows from logged gullies persisted as steeper slopes were logged (Tripp 1994).

Chronic surface erosion from logging roads can degrade water quality, resulting in impacts on both domestic water supplies and fish habitat. Suspended solids in some community water supplies have increased as a result of road slope failures and surface erosion (e.g., Chapman and Mashiter Creeks in the Squamish Forest District). Also, studies in the central interior of the province have demonstrated that transport of fine sediments from logging roads and skid trails, located in terraced lacustrine soils, can impact water quality, fish spawning gravels, rearing areas and aquatic insect abundance (Slaney et. al. 1977a, 1977b). In May to July, mean suspended sediment concentrations were 37 mg. L⁻¹
(peak 257 mg.L⁻¹) in upper Centenial Creek (logged) and 75 mg.L⁻¹ (peak, 467 mg.L⁻¹) in lower Centenial Creek (logged with terraced lacustrine road settings) versus 14 mg.L⁻¹ (peak, 60 mg.L⁻¹) in the adjacent unlogged Donna Creek. Amounts of fine-sediment deposition (clays, silts and fine sands <0.3 mm diameter) in simulated spawning redds were a function of sediment loading (or dose) from May to July (P<0.05 [Fig. 1]; scouring of a course sandy bar near the sample sites caused the high variability in the <1.19 category in the control). Revegetation of erodible road slopes by hydroseeding was necessary to retard sediment transport from the silty side-slopes of logging roads (data on file).

There is also recent evidence of a more subtle negative feedback impact of logging (or overfishing) because a depression in spawner carcasses reduces the availability of nutrients that support the salmonid food chain (Schuldt and Hershey 1995). Coastal and many interior streams in

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**Fig. 1.** Deposition of sediment in spawning habitat study sites at Centenial Creek (logged) and Donna Creek (unlogged) during mid-spring to mid-summer as a function of concentration x duration (mg.L⁻¹ days; vertical lines are 1 standard error) (from Slaney et al. 1977).
British Columbia are oligotrophic, with dissolved inorganic phosphorus concentrations less than or near detection limits of 1 μg.L⁻¹ (Slaney and Ward 1993). Recent studies of the nutrient and carbon movement in food chains of a small coho salmon stream have demonstrated that returning salmon spawners provide 30 to 34% of the nitrogen and carbon to juvenile salmonids (Bilby et al. 1996). Because survival of salmonids through freshets is strongly correlated with fish size reached by fall in streams (Scrivener and Brown 1993; Quinn and Peterson 1996), or size at migration to a larger waterbody (Burrows 1994) or in the ocean (Ward and Slaney 1988), the abundance of fish carcasses is potentially crucial to maintenance of fish populations that rear in streams (e.g., trout, char, chinook salmon and coho salmon). Runs of adult fish may continue to decline as logging impacts increase, returning less nutrients and carbon to already nutrient-carbon deficient streams, particularly if combined with overfishing of a (now) less productive stock (Larkin and Slaney 1996).

Past logging practices of mature and old-growth trees to the stream bank of both small and large streams have probably had the greatest impact on the habitat of rearing and resident fish. This is because of the reduction in availability of large woody debris (LWD) from mature conifer windfalls, but also the result of reductions in streambank stability within the flood plain of streams (Murphy 1995; Koski 1992). During the 1950s to the 1970s, many fisheries managers believed that the introduction of woody debris in streams impaired fish production by creating impassable jams or scouring channels, and a previous section of the Canadian Fisheries Act promoted its removal from streams during the 1960s to 1970s. Clearance of log jams was widely practised in the Pacific Northwest. However, more recently, it has been clearly demonstrated that the loss of LWD in stream channels (versus small organic debris) results in a serious long-term decline in the complexity and diversity of aquatic ecosystems, including fish habitat, requiring 100 to 200 years to recover naturally (Fig. 2, Koski 1992). Because approaching half of the provincial forest has been logged, including the riparian zone of most of the salmonid streams at lower elevations, a serious LWD deficit continues to worsen. The effects of streambank logging at Carnation Creek on the production of coho smolts has been initially moderated or initially offset by the remaining old-growth LWD in the mainstem and the preservation of off-channel overwinter habitat (logging roads were excluded from the flood plain), but also by modestly elevated stream temperatures (Holtby 1988). Regardless, since logging (1976–81), both the average return of mature coho adults per smolt and the average coho fry abundance in late summer have declined, suggesting a significant decline in stock productivity (from a stock-recruitment perspective). Although there was no systematic paired external control (unlogged) for the Carnation Creek case study, a gradual declining trend in coho production from the mainstem is predictable, because only limited mature large wood is available for recruitment from the logged riparian zone (Scrivener and Brown 1993; P. Tschaplinski, Ministry of Forests, personal communication). Moreover,
Fig. 2. A model of changes in the amount of large woody debris (LWD) in small (2nd and 3rd order) streams after clearcutting without a buffer strip along the banks. The decline in remnant prelogging LWD was calculated from the natural depletion rate as a result of decay, abrasion and export. Second-growth was based on yield tables for western hemlock-sitka spruce stands on productive valley bottom sites; post-logging LWD is generated from second growth (from Koski 1992).

the abundance of chum salmon and steelhead trout have been depressed because of impacted spawning and over-wintering habitat in the mainstem of Carnation Creek (Scrivener and Brown 1993).

Streamside logging to the banks seriously impacts over-wintering habitat, reducing the abundance of juveniles that survive winter freshets (Fig. 3, Koski 1992). A buffer strip or riparian management zone provides much of the future supplies of large woody debris by bank erosion and from mature tree windfalls, but the zone also provides deciduous leaf litter, and protects other overwintering areas as side-channels, alcoves, off-channel ponds, as well as access to small tributaries (Murphy et. al. 1986). Buffer strips of mixed vegetation types also moderate excessive increases in stream temperature, especially in southern latitudes and most lake-headed streams. Logging to the streambanks has left most low-land banks with deciduous canopies, some up to 50 years old, or with immature conifer forests at higher elevations. These trees provide little permanent large woody debris as windfalls, and also encourage beaver damming activity on small streams. Although summer habitat may be initially maintained by deciduous (alder) canopies, as the old-growth wood in the channel decays or shifts, habitat becomes simple and monotypic, resulting in fewer fish over-wintering successfully to the smolt stage (Fig. 3, Koski 1992). This impact is most severe for species that expend a year or
more in streams, including steelhead trout, coho salmon, bull trout, Dolly Varden, rainbow trout, cutthroat trout, Arctic grayling and some chinook salmon stocks.

Losses of LWD are particularly perverse because many of these alder-lined streams appear aesthetic or idyllic, but they lack sufficient diversity and complexity for the successful overwintering of salmonids. Without human reintervention, these streams will not recover naturally for one to two centuries (Fig. 4, Koski 1992), and habitat will continue to deteriorate for at least another half-century. The scale of past streambank logging in the province will likely result in costs to rehabilitate streams (at about $50,000 to $60,000 per km, where feasible) that are equivalent in magnitude to the costs required for the province-wide stabilization of hillslopes (Slaney 1994).

Scale of Restoration and Rehabilitation Needs

As with forest regeneration after harvesting, there is a compelling case that watershed resource managers are responsible to future generations to accelerate the recovery process of impacted watershed ecosystems and, if necessary, mitigate impacts that would otherwise persist. In the early era of fisheries management and into the 1980s, hatchery fish were perceived as a panacea for restoring fish stocks depressed by over-

**Fig. 3.** Relationship between coho salmon parr density in winter and different logging treatments of stream reaches. Coho parr density was much greater in old-growth reaches than in clear-cut reaches; bars are 95% confidence intervals (from Murphy et al. 1986 and Koski 1992).
Fig. 4. Relationship between the volume of large woody debris (LWD) in streams and the density of coho parr in winter (from Koski 1992).

fishing, hydroelectric dams, pollution and other forms of land-based habitat degradation. This option had appeal because it required less regulatory control over developers and land managers, but in the long term, wild fish and their habitat deteriorated further (Netboy 1981, Cederholm 1993). However, a more integrated watershed approach to protecting (new logging) and restoring (past logging) the productivity of wild fish streams had not been widely attempted. Sceptics have cited a high incidence of early failures as evidence that rehabilitation of fish habitat is generally uncertain (Calhoun 1966; Miles and Hartman 1995), although much of the pioneering work was done with only limited knowledge of stream geomorphology, sediment routing and energy dissipation. More recent advocates of stream restoration emphasize acceleration of natural recovery processes, including nutrients, with emphasis on use of natural morphological features (as templates), based on both sound structural designs of structures and fluvial science, as well as wisdom obtained from past trials and misapplications (Slaney 1994; Hartman et al. 1996).

Restoration, or more aptly rehabilitation, must be approached from an integrated perspective, in recognition of the interconnections between physical and biological processes within a watershed unit. Restoration targets thus include logging-impacted hillslopes, gullies, riparian areas, stream channels and estuaries. Restorative activities within a watershed are conducted on a priority basis, ranking impacts and risks of impacts. Watershed assessments, including condition of roads, slopes, gullies, riparian zones and fish habitat of streams, are conducted by setting prior-
ities for site prescriptions for preventative and rehabilitative treatments. Broader incorporation of terrestrial ecosystems in the provincial forest is being coordinated within an enhanced silvicultural program, promoting timber production and restoration of landscape interconnectivity in the longterm.

Initially, a greater proportion of restorative effort and funding needs to be directed at the hillslopes to accelerate slope stabilization and to reduce mass wasting or chronic erosion which affect water quality and fish habitat located downstream. Then, as hillslope impacts are stabilized and replanted with trees, more effort is directed at rehabilitating riparian and fish habitat in stream channels that were historically impacted, some 50 to 60 years ago. A set of nine procedural guides form the technical standards for assessments, prescriptions and remedial activities, linked to province-wide training initiatives.

The backlog of logging-impacted watersheds with significant road failures and erosion is immense. Preliminary estimates indicate that it would cost several hundred million dollars to manage all impacted hillslopes because there are an estimated 130,000 km of non-status and abandoned roads (Anon 1993). The number of landslide scars and gullies requiring remedial treatments is unknown. Similarly, it is not yet known how many streams will require rehabilitation to accelerate the recovery process, or to offset habitat losses. However, it is known that it requires between 100 and 200 years to recover large woody debris from mature windfalls (Fig. 1, Koski 1992). The cost to restore or rehabilitate riparian areas and fish habitat in streams is expensive — about C$50,000 to $60,000 per km of stream (D. Heller, U.S. Forest Service, personal communication 1993), which has been confirmed in British Columbia, and C$15,000 per hectare of riparian area, including stream banks (Koski 1992). Assuming that about 2,000 salmon and resident fish streams have been logged to the streambanks for an average distance of 10 km, then 20,000 km may require stream and/or riparian rehabilitation, or equivalent in cost to hillslope restoration. (There are 2,576 known salmon streams alone in British Columbia.) This equates to a potential need of 20 to 40 years of hillslope and stream rehabilitation in British Columbia at $50 to $100 million per annum.

**Hillslope Restoration**

Road crews undertake road deactivation and rehabilitation to return unneeded road areas to tree production, and retained road systems are "storm proofed". Contractors utilize heavy equipment (excavators and dump trucks) and hydroseeders to stabilize eroding cut-and-fill slopes of roads, landslides and eroding steep slopes. Overloaded road-fill slopes, often indicated by tension cracks, are indentified and resloped to prevent landslides. Natural drainages are reestablished on retained roads by the excavation of waterbars, cross ditches, "Squamish culverts" and engineered fords. Roads are also improved by narrowing surfaces, resurfacing,
outsloping and fluming of culverts on fill slopes, as well as increasing numbers of culverts to restore natural drainages (Chatwin et al. 1991). Revegetation through reseeding is a priority to arrest soil erosion and sediment transport to streams from disturbed soils. During road deactivation, opportunities to reestablish wildlife browse and snags for cavity nesting birds are realized. Eligibility criteria for funding of road rehabilitation under the program have been developed to ensure restoration funds are not diverted into upgraded road maintenance to access new cut-blocks, which is managed under the new Forest Practices Code.

Crews are also engaged in removal of excess logging debris from gullies, thus reducing the risk of debris flows in those gullies assessed as hazardous to downstream fish, water and forest values. Stabilization works, including check dams, energy dissipation devices, geotextiles, wattles and revegetation, are employed where gullies have “torrented” or slumped in debris flows. Debris hazards in gullies have been identified by audits as primary causes of “debris-torrenting” into fish-producing streams (Tripp 1994). Thus, storm proofing of historically impacted gullies and gullies at risk of debris flows are high priorities early in the program.

Small crews are also needed for labour-intensive work controlling erosion from unstable and fine-textured soils by extensive tree planting, terracing and brush layering. Hydroseeding (using soil binders, mulches and fertilizer) from large tanker and pickup trucks, as well as by hand seeding using cyclone seeders, are employed to arrest erosion and sediment transport to drainages (Chatwin et al. 1991). Steep open slope failures may require “heli-seeding” and mulching to stabilize them. Eroding fill- and cut-slopes, skid trails and landings are stabilized, thus conserving soil for growing sites, improving water quality and minimizing impacts to fish habitat. Efforts will be made to utilize native plants and shrubs and grasses.

Standard silvicultural methods are used to reclaim deactivated roads, as well as side-cast fills along roads and slope failures (landslide scars), as part of the productive forest land base. Steeper unstable fill-slopes are hand-trenched and revegetated by hand-wattling. Modified and innovative silviculture will be needed to assure sites are erosion proofed rapidly, and replanted with vegetation conducive to resource values, including wildlife, biodiversity and forestry. The economic benefits in reclaimed timber values in severely impacted watersheds, such as the Gordon River (approximately 500 landslides), will be significant in the long term.

**Riparian and Restoration**

Prior to the Coastal Fisheries-Forestry Guidelines of 1988, there was no provision for leaving strips of mature or old-growth trees to contribute to LWD, to maintain fish habitat and aquatic biodiversity, and to provide windfalls as coarse woody debris for riparian biodiversity. Similarly, in the interior of the province, protective leave strips were only left on
streams and lake shores with higher recreational fishery values. Such practices have either resulted in streams malfunctioning, where large wood recruitment has been reduced substantially, or becoming geomorphically non-functional, whereby past logging of the floodplain to the banks causes channel widening or unravelling. The latter results in considerable channel instability (Kellerhals and Miles 1996) and thereby a loss of viable fish habitat. The abundance of fish in streams (and probably lake shores) is closely related to habitat complexity provided by large woody debris recruitment (Fig. 4, Koski 1992; Scrivener and Brown 1993). Since it is now recognized that it will require more than a century to reestablish large mature trees, rehabilitation of fish habitat in channels will be required in stable streams to bridge the time-gap of natural availability of large woody debris. In contrast, in-stream restoration of structure in non-functional streams is not feasible in the short-term until natural geomorphic functions of the riparian zone have recovered, as emphasized by Kellerhals and Miles (1996).

Riparian selective spacing, replanting and tending will greatly accelerate ecologically balanced native mixes of deciduous and conifer trees (roughly 40 to 60%), as well as shrubs, to provide, in the long term, natural riparian functions. Deciduous stands of alder and poplar, in particular, are a challenge because after thinning and replanting of the spaces with advanced young confers, several years of seasonal tending and protection from browsing is required, thus requiring a continuing stewardship role by licensees and/or conservation groups. The key aquatic function is to provide streamside sources of mature trees as large woody debris that provide both summer and winter fish habitat. Other key aquatic functions are large root masses from mature conifers and deciduous trees for bank stability, provision of deciduous leaf litter at the stream-bank, nutrient supply from nitrogen-fixing vegetation (e.g., red alders) and, in some settings, rapidly growing deciduous trees on the banks for temperature moderation or erosion control. Riparian assessment and restoration crews are highly diversified, including technical specialists (fish habitat biologists, silviculturists, forest ecologists, wildlife biologists and related technical staff) and forest workers (fallers, spacers, planters, trained equipment operators and manual labourers). As a critical interface, the riparian zone may require special treatments because fish habitat, both in the mainstem by LWD and off-channel in overwintering areas, is a sensitive fish and wildlife zone, which is well recognized in the Forest Practices Code. Restoration of the riparian zone provides an opportunity as an interface to integrate forestry and fisheries, striving for both aquatic and terrestrial biodiversity.

Stream Rehabilitation

Past logging and road building practices also frequently cut off fish producing side-channels and ponds as well as smaller water courses that
are utilized as over-wintering refuges. As a first priority in habitat assessments, all culverts and crossings are assessed for the passage of fish, and especially overwintering juveniles. Steep extended culverts are typically impassable to migrant fish, particularly juveniles. These will be replaced or baffles installed to facilitate migration. Perched or elevated culverts are a common problem, and fish passage is restored by backwatering, installing stable drop-structures or replacing the culvert. Similarly, historical side-channel refuges isolated by roads or debris flows are reopened to fish access as overwintering refugia.

In many streams, large woody debris was removed from the channel by forestry-fisheries "practices of the day", and logs and rootwads were typically left on stream banks or nearby. The number of pieces of large wood in streams logged to the streambanks is typically reduced to <1 to 2 pieces per channel width, whereas >3 pieces per channel width is common in unlogged streams (Johnston and Slaney 1995). (This respectively equates to <100 to 200 and >300 pieces per km in second- and third-order streams.) In geomorphic stable settings, stream rehabilitation crews rewinch or place some of the more preserved logs and log-rootwads into the channel. These will be secured by trained forest worker crews using well-tested methods of the U.S. Forest Service on national forests in the Pacific Northwest. Where required, excavators are utilized to build small streamside access trails or tote-roads and to install instream structures, including log-rootwad-boulder complexes. Where access is difficult or if there are environmental risks, helicopters are frequently used to sling in 500- to 700-kg boulders and logs. Costs can be similar to tote-road access (Ward and Slaney 1979), but two- to threefold greater with larger capacity helicopters for larger boulders and rootwads (1,000 to 1,500 kg). Crews will install boulder clusters and armour eroding "toes" of banks with boulders and "whole-tree retards". Boulder and boulder-secured log armouring, brush matting, geotextiling, cut-tree staking, and planting of deciduous cuttings and rooted tree stock on upper-streambanks are employed to reduce bank erosion and restore riparian ecological functions at the streambank interface. Instream large woody debris (LWD) is restored either by secured placements or by debris-trapping techniques, thereby also recapturing pockets of spawning gravels in impacted streams (although spawning sites rarely limit stream-rearing species). Larger excavator and earth-moving equipment is used to reroute and restore diverted channels, where logging-induced bedload aggradation has rerouted streams into riparian forest lands on historically logged floodplains.

LWD restoration in smaller streams has been demonstrated by the U.S. Forest Service to withstand 35- to 75-year floods of 1990 in the Mount Baker Snoqualmie National Forest (Doyle 1991; loss rate approaching 10%). Salmonid smolt production is dependent on these near-natural structures, as has been recently demonstrated by a 6-year intensive study at Porter Creek, near Olympia. Coho smolts have been increased about fourfold by systematically securing large wood in the channel, but the
benefits to salmonid abundance were not detectable until post-winter (J. Cederholm, personal communication 1996). Similarly, numbers of coho migrants at two streams in Oregon were increased three- to fivefold by restoration of large wood in the channel (Solazzi 1992 in Murphy 1995) "Mentorship" and on-site training of workers is necessary to assure that the most successful techniques are repeated with precision, and that less reliable techniques such as cross-stream structures (v-logs) are generally avoided unless the stream is small and very stable (Frissel and Nawa 1992; Ward and Slaney 1993).

Restoration of fish habitat has been less successful in larger streams which have not been storm proofed or are naturally unstable (Doyle 1991; Ward and Slaney 1993; Olson and Doyle 1996). Initial inspections of 400 LWD structures was conducted after record storm flows in 1996 in central coastal Washington (post >50-year events of mid-winter) in restored tributaries of the White River. Percentages of functional structures (in-place, including 10% moved) were 80, 78 and 86% in West Fork White, Hucklebury and Greenwater creeks, respectively. Failed structures (lost or buried) were mainly log deflectors and log cover secured within depositional channels, and were frequently associated with streambank erosion and road failures (Olson and Doyle 1996). Failures are also predicted for streams that are severely degraded by morphological changes, and these must be avoided as potential candidates (Kellerhals and Miles 1996). In these cases, offsetting off-channel work is the only viable option to preserve stocks of fish at risk in the short-term, other than accelerating natural recovery processes by storm proofing hillslopes and restoring riparian functions for the long term.

A design target to withstand a one in 50-year flood event has a reasonable probability of at least 20 years of functional durability, which has economic support in benefit-cost analyses of fish habitat improvement projects (minimum duration of 10 years, e.g., Ward and Slaney 1979). However, it is critical that hillslopes have either naturally stabilized or are storm proofed, because recent experience in the Pacific Northwest has demonstrated that in-stream structures can be damaged by hillslope-generated debris flows (e.g., Fish Creek, Oregon [J. Doyle and D. Heller, U.S. Forest Service, personal communication 1996]). Recovery of fish populations has been attributed to combined hillslope and stream restoration. Large populations of summer-run steelhead and coho salmon have recovered from near extinction at Deer Creek, a larger stream, in Washington, to about 40% of their historical abundance (Kraemer 1994; Doyle et al. 1995).

In some salmonid streams that are relatively stable, more technically complex in-stream structures are required to accelerate recovery of fish holding and spawning sites, especially where the natural pool-riffle sequence has been lost, there is a lack of mature trees to recreate natural log jams, or there is risk of dislodgement of simple LWD structures (i.e., in larger streams). Where steeper stream sections (>2% gradient) have been channelized or simplified, complex pool-riffle sequences are reestablished by use of steep low-profile boulder ramps that are keyed into the
banks on a frequency of six channel widths using a template profile as described in Newbury and Gaboury 1993. Pools and runs can also be reestablished with opposing wing deflectors in uniform sections of larger streams. In both approaches, backwatering as shallow extended pools needs to be minimized, incorporating attached LWD in the pools as in natural old-growth templates. Also, woody debris catchers and artificial log jams can be installed in the more stable reaches that are deficient in habitat complexity owing to past stream logging practices (Ward and Slaney 1993). Submerged stream reefs constructed of logs rafts weighted with cobbles and boulders, and analogous to the well-proven artificial marine reefs, are a bioengineering innovation being tested in the program. Where stocks of fish are depressed and streams are oligotrophic, nutrient and carbon inputs to stream ecosystems may be limited by the availability of spawner carcasses (Bilby et. al. 1996; Schuldt and Hershey 1995; Larkin and Slaney 1996). Streams in British Columbia are typically highly infertile and the food chain of fish is phosphorus and, to a lesser extent, nitrogen limited. In highly destabilized streams that retain some over-wintering habitat, there may be no other option other than attempting to increase smolt production by low-level nutrient addition, provided some structural elements remain. The overwinter survival of salmonids is positively correlated with the size juveniles attain by autumn, to the degree that a 1-cm increase in size of fall-fry may double their overwinter survival (Scrivener and Brown 1993; Quinn and Peterson 1996). In destabilized oligotrophic streams with depressed returns of migrant fish, seasonal low-level stream fertilization can accelerate summer growth and overwinter survival of salmon and trout, as an inexpensive interim measure to accelerate recovery in oligotrophic waters. At Grilse Creek and the unstable Salmon River on Vancouver Island, the mean weights of steelhead underyearlings and parr were increased two- to threefold over a distance of 15 km by use of inexpensive low-level nutrient additions (Fig. 5; from Slaney and Ward 1993). Once-annual applications of slow-release nutrients as compressed "nutri-stones" are being applied in several streams and off-channel habitats in the province where prescribed as beneficial to ecosystem recovery from oligotrophication.

**Off-Channel Habitat Restoration and Mitigation**

In streams where the recovery of channel stability will require decades, off-channel habitat restoration and mitigation projects are undertaken to create stable groundwater or intake side-channels. About 100 of these have been constructed and successfully maintained with minimal maintenance over the past 15 years, most by the Resource Restoration Division of the federal Department of Fisheries and Oceans, including 40 groundwater channels, up to 1990, which were designed for production of chum and coho salmon (Bonnell 1991). Because of the higher risks of instream structural failure in unstable non-functional streams,
Fig. 5. Trends in mean weights of juvenile steelhead and rainbow trout within control (C1, C2), fertilized (G5 to S27) and unfertilized downstream sites (S38, S50) in Grilse Creek and the Salmon River in 1990 and 1992 (G = Grilse Creek and S = Salmon River). Spacial controls were located 1 km upstream in Grilse Creek and the Salmon River. Mean weights were 2- to 3-fold greater by early September in the reaches drip-fertilized with liquid N and P from mid-spring to mid-summer (from Slaney and Ward 1993).

off-channel projects are one of the most common technical options employed at larger streams by the Watershed Restoration Program. Groundwater channels are typically very productive because of their stability, groundwater sources of nitrogen and the contributions of salmon eggs and carcasses to phosphorus and nitrogen, and to energy flow as carbon. Restored side-channels can produce 1.6 adult chum salmon per square meter. High levels of coho smolt production have been documented (0.5 to 1.0 smolts per m² on average from complex deep ponds and boulder-lined channels, resulting in 0.07 to 0.09 adults per m² [Adams and Whyte 1990]). Juvenile steelhead and coho migrate into channel-pond complexes to overwinter, and woody refuges in the channels and within the deeper (>2 m) areas of the ponds provide wintering refuges for these and other rearing species (M. Foy, personal communication 1996; Department of Fisheries and Oceans, data on file; Cederholm 1988). There is also support for use of groundwater pond-channel complexes in interior stream systems that are subject to anchor ice impacts because adult and juvenile cutthroat trout utilize such overwinter refugia (e.g., Elk River). The productivity of oligotrophic channels with surface intakes can also be improved by annual applications of slow-release nutrients, until provided
naturally by species such as chum salmon and sockeye or kokanee spawners.

**Program Benefits and Evaluation**

The Watershed Restoration Program will contribute to increasing forest site productivity. Although benefits to timber supply may be minor on a province-wide basis, such benefits will vary greatly by watershed according to area of road surfaces and the magnitude of hillslope impacts and their revegetation. The program will focus on restoring vegetation on deactivated roads, landslide scars, and unstable cut- and fill-slopes of roads. Evaluations are required to estimate the potential benefits in timber associated with replanting road, slope and gully areas impacted by past logging practices.

The program will also protect and improve aquatic habitats of wild fish stocks that contribute to fresh- and salt-water sport, and commercial and aboriginal fisheries, which generate considerable benefits annually in the province. A major program could increase freshwater survivals of wild anadromous fish in impacted watersheds by up to twofold by improving stock productivity. Survivals of salmon and steelhead in freshwater are typically less than 10%. Hillslope and channel restoration that substantially reduce erosion could double freshwater survival of wild fish, strengthening the productivity of weak fish stocks to sustain harvest. Similarly, projects that restore habitat complexity in streams or improve habitat productivity can readily increase salmon and steelhead smolt output by at least twofold on average, and thus, combined with gains in stock productivity, can at least double the number of adult fish that can be potentially caught. Results of in-stream population estimates of juvenile steelhead and coho salmon (Ward and Slaney 1979), and enumerations of coho smolts in coastal Oregon and Washington (Solazzi 1992, in Murphy 1995; J. Cederholm, Washington Department of Natural Resources, personal communication 1996) provide convincing support that three- to fivefold improvements are achievable in smaller stream systems with sparse LWD. Catchable-sized resident fish populations, supporting highly valued sport fisheries in British Columbia, can be re-established as well.

Stocks of wild fish at risk will receive greater priority to strengthen their productivity. These stocks are typically vulnerable because of the double-barrelled impact of overharvest in commercial fisheries targeted on more productive salmon stocks and because habitat impacts reduce their survival rates. A cooperative integrated approach with fisheries management agencies and commercial and sport fishing associations will be needed to assure that sustainable benefits are generated by focusing restoration on weaker stocks of fish within a drainage basin.

Greater biodiversity of fish and wildlife will result from more diverse and complex habitats in stream channels, riparian zones and on
revegetated hillslopes, which will be an added benefit of the Watershed Restoration Program. The riparian zone will provide primary benefits because it is a critical corridor and interface that >90% of wildlife species depend upon for at least one stage in their life history. Also, the health of the fish community depends on the natural ecological functioning of the riparian area, as described earlier.

Water quality will improve, particularly in watersheds with significant fishery and domestic water values. As indicated by water quality criteria, the water quality necessary for sustaining good salmonid production also ensures adequate quality for community water supplies. Reductions in community water treatment costs at some rehabilitated watersheds will be an immediate benefit, albeit the numbers of impacted community watersheds are relatively few.

To ensure selection of the most beneficial watershed restoration projects on a regional basis, "biostandards" have been developed by the program for estimating and predicting the benefits derived from improved fish habitat. These also provide a first-level prediction of benefits in advance of more intensive evaluations.

The Watershed Restoration Program will primarily benefit the smaller communities adjacent to timber-producing areas where timber shortfalls are forecasted. Such communities occur in all regions of the province. The Watershed Restoration Program, funded by Forest Renewal BC, a provincial crown corporation, is designed to diversify employment and stewardship opportunities in resource-dependent communities, while restoring the productive base of existing logging, fishing and tourist industries. Much of the training and the employment can be community-based. To the extent that the Watershed Restoration Program fosters community-based stewardship of natural resources, the program will help establish more sustainable, community-centred economies by improving the resource base available to generate traditional employment.

Project evaluation is essential to improve program effectiveness as the program proceeds, and to demonstrate program effectiveness or "wise spending" in the long term. Project evaluations will determine what techniques are most effective in which settings, and will be used to capture innovations. Monitoring of overall program effectiveness will largely be accomplished by more intensive evaluation of a subset of replicated logged watersheds established in treated and untreated (control) pairs. Comparisons to biostandards (streams, side-channels and ponds) or silvicultural standards (riparian zones and hillslopes) may also be utilized as indicators of benefits where pairs are unavailable for operational monitoring of projects.

It is anticipated that the primary benefits of accelerating natural recovery processes via the Watershed Restoration Program will be to fish production, which should be substantial, provided experience in effectiveness monitoring is transferred rapidly through province-wide training initiatives delivered at demonstration sites in forestry-dependent communities. The success of the Forest Practices Code will also depend
on the effectiveness of restoration (and vice versa) because of the inter-
connections of biological and physical processes in logged watersheds
subject to further forest harvesting. The challenge to the program and its
habitat biologists, engineers, geoscientists and silviculturists will be to
efficiently achieve a net-gain of productive habitats on a sufficient scale to
ensure the legacy of resource values from our forested watersheds are
inherited by succeeding generations of British Columbians.

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