CHAPTER 3

Gravel galore: Impacts of clear-cut logging on salmon and their habitats

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While droughts, floods and debris torrents are part of natural cycles, timber harvesting leaves the landscape more vulnerable to these events. In extreme cases, landslides that follow logging can yield so much gravel and cobble substrate that the stream's transport capacity is overwhelmed, and the stream ceases to flow above ground, disappearing instead into a matrix of rock. This photo of cobbles and gravel was deposited in a debris torrent caused by upstream logging, filling a tributary of the Sarita River on Vancouver Island.
PHOTO: Brendan Hicks

Introduction

Timber harvest may have both direct and indirect effects on salmon, and with a few exceptions those effects result in lowered survival of salmon in their stream habitats compared with unlogged forest (Hicks et al. 1991b). Some impacts may be seen immediately or shortly after logging, whereas others can take decades to be expressed. Central to analyzing these effects is the context of the freshwater environment in which salmon are spawned and reared, and the life histories of the salmon species. This chapter will examine the effects of timber harvest on the freshwater habitat and life stages of salmon. It will also investigate the hypothesis that the salmon species least affected by timber harvest are those with the least reliance on stream habitats.

The north and central coasts of British Columbia extends from latitudes 50°N to 54°N and occupy the Pacific Maritime ecozone. Average annual runoff ranges from 1000 to 3000 mm. Summers are drier than other months; only 15% of the total annual rainfall of 2907 mm fell at Prince Rupert Park in the three-month period of June to August (Table 3-1). The coastal climate is one of extremes, with up to 4.5% of the total annual precipitation falling in a single day. Snow generally falls from November to April. Outside of cities such as Prince Rupert and Kitimat, communities are small and isolated. The primary source of watershed development is forestry.

TABLE 3-1
Mean monthly totals of precipitation at Prince Rupert Park, British Columbia (54° 18' N 130° 20' W, 91 m altitude) from 1959 to 1990. Ten millimeters of snowfall is equivalent to 1 mm of rainfall.
Source: Environment Canada.

	Precipitation (mm)				
Month	Total precipitation	Total rainfall	Total snowfall	Extreme daily rainfall	Extreme daily snowfall
Jan	311	271	396	107	305
Feb	266	237	292	112	394
Mar	248	222	258	84	343
Apr	261	251	100	110	386
May	169	169	3	57	38
Jun	141	141	0	71	0
Jul	117	117	0	74	0
Aug	174	174	0	86	0
Sep	263	263	0	139	0
Oct	437	437	6	135	76
Nov	341	325	158	106	267
Dec	339	301	377	139	406
Year	3066	2907	1588		

					Average size at maturity	

Salmon life histories

Timber harvest does not have the same influence on all salmon species. To understand the effects of timber harvest on salmon, we must understand the variety of their life histories, and especially the range of their reliance on freshwater habitats. Five salmon species of the genus *Oncorhynchus* spawn in gravel nests (redds) in forest streams of the north and central coasts of BC. All the adult salmon die after spawning, but the species vary in their ties to freshwater.

Pink

Pink salmon (*O. gorbuscha*) are distinguished from other Pacific salmon by their fixed, two-year life cycle (Table 3-2). The pink salmon of a single river system that spawn in odd and even years are reproductively isolated and have developed into genetically distinct sub populations. They are the smallest salmon species, averaging 1.0-2.5 kg at maturity, and the young migrate to sea as fry soon after emergence from the redd. Large, maturing males develop a marked hump-back. The spawning migrations into freshwater are short; most spawning takes place within a few kilometers of the sea or in intertidal reaches, and occurs from August to November (Heard 1991).

TABLE 3-2
Life history characteristics of the Pacific salmon species found in the north and central coasts of British Columbia.
Source: Department of Fisheries and Oceans, Canada.

Salmon species	Time rearing in freshwater	Primary early rearing habitats	Time spent at sea (years)	Average age range at maturity (years)	Average size at maturity	
					Fork length (cm)	Weight (kg)
Pink	hours to days	estuary	1.5	2	45	1.8
Chum	hours to days	estuary	2.5-4.5	2-7	65	5.5
Chinook	1 month to 1 year	stream, estuary	1.5-4.5	2-8	90	16
Coho	most 1-2 years	stream	0.5-1.5	2-4	55	4.5
Sockeye	1 to 2 years	lake	1.5-3.5	3-8	65	2.3

Chum

Chum salmon (*O. keta*) are large, strong swimmers capable of a maximum swimming speed of 3.05 m/s, with burst speeds up to 4.6 m/s. However, they do not leap, and are reluctant to enter long-span fish ladders; their upstream migration in a river is stopped by the first barrier of significance. In rivers without barriers they may migrate 400-900 km inland, moving rapidly at 40-50 km/day. They may also spawn in intertidal reaches. Chum salmon in British Columbia spawn in early autumn at 2 to 7 years of age (Table 3-2). They are second in size only to chinook salmon, and individuals may be up to 110 cm long and weight 21 kg. Chum salmon, like pink salmon, have a short freshwater life, migrating to the sea as fry shortly after emergence from the gravel. (Salo 1991).

Chinook

Chinook salmon (*O. tshawytscha*) appear to have evolved a variety of juvenile and adult behavior patterns that spread the risk of high mortality in any one year. Spawning occurs from near tidewater to over 3,200 km upstream in the headwaters of the Yukon River. Chinook salmon in the north and central coastal streams of British Columbia, like all the races south of latitude 56°N, are predominantly "ocean type", which means that most juveniles migrate to sea during their first year of life, normally within three months of emergence from the redd. However, in northern rivers such as the Nass and Skeena Rivers, the juveniles are of the "stream type", spending one or more years in freshwater as juveniles before migrating to the sea. In these rivers, adult chinook salmon migrate into rivers in a single peak in June. In the Bella Coola River, an early run in late May and June is followed by a later run in August. All chinook appear to spawn in the fall, regardless of the run timing. Ocean-type adults return to freshwater at ages 3-4, though males tend to be younger that females, with a proportion returning as age 2 fish (Healey 1991). Chinook are the largest of the Pacific salmon, and may exceed 45 kg in weight.

Coho

Coho salmon (*O. kisutch*) migrate further upstream than pink or chum salmon, but not as far as sockeye or chinook salmon. Coho seldom migrate more than 240 km upstream to spawn, with a few exceptions; in the Skeena River, for instance, coho salmon migrate 510 km upstream. Entry into freshwater takes place in September and October, and spawning occurs in small tributaries. Fry emerge from the gravel in the following spring, and spend summer and the following winter rearing in the stream, if they are not displaced by floods. Fingerling coho salmon transform into smolts in spring, and migrate downstream to the sea. Most coho salmon in British Columbia return to spawn as three- year olds, having spent one winter in fresh water and one winter at sea, but some return as fouryear olds, spending two winters in fresh water before migrating to sea (Table 3-2). At their return to fresh water, coho salmon weigh 3-4 kg, and fish up to 6 kg are not unusual; the largest coho salmon on record weighed 14 kg (Sandercock 1991).

Sockeye

Sockeye salmon (*O. nerka*) are the third most abundant of the Pacific salmon species, after pink and chum salmon, and exhibit the most variety of life history patterns. Mature adults weigh 2-3 kg. Juveniles make use of lakes for early rearing, and lake-locked populations (kokanee) mature, spawn, and die in freshwater. Reliance on lake habitats seems to require more precise homing to spawning areas than in other salmon species. However, the success of this adaptation to lake rearing is shown by the greater abundance of sockeye salmon than chinook and coho salmon that rely solely on stream rearing. The Skeena River system is the second largest sockeye system in British Columbia

after the Fraser River. Rivers Inlet and the Nass River are also important sockeye systems. Sockeye salmon generally spawn in late summer and autumn, and fry emerge from the gravels in spring and move to the littoral areas of lakes. They rear in the lake for one or two years (Table 3-2), and then migrate to the sea in May or early June, where they spend two to three years (Burgner 1991).

The foundations of stream ecosystem function

Streams and river ecosystems generally function as a longitudinal continuum, and the relative importance of different energy sources changes from upstream to downstream (Vannote et al. 1980). The ecosystems in narrow streams (less than about 4 m wide) are supported by energy inputs of leaf litter from riparian vegetation. In wider streams and rivers, the ecosystems are supported directly by the sun through photosynthesis of aquatic algae and plants, or by material transported from upstream reaches. At the reach scale, a stream's flow brings particulate and dissolved organic matter from upstream, on which the downstream reach can capitalize (Figure 3-1).

FIGURE 3-1
Changes in the importance of energy sources with increasing stream width and stream order (from Murphy & Meehan 1991, after Vannote et al. 1980).
P = photosynthesis, R = respiration, and FPOM = fine particulate organic matter.
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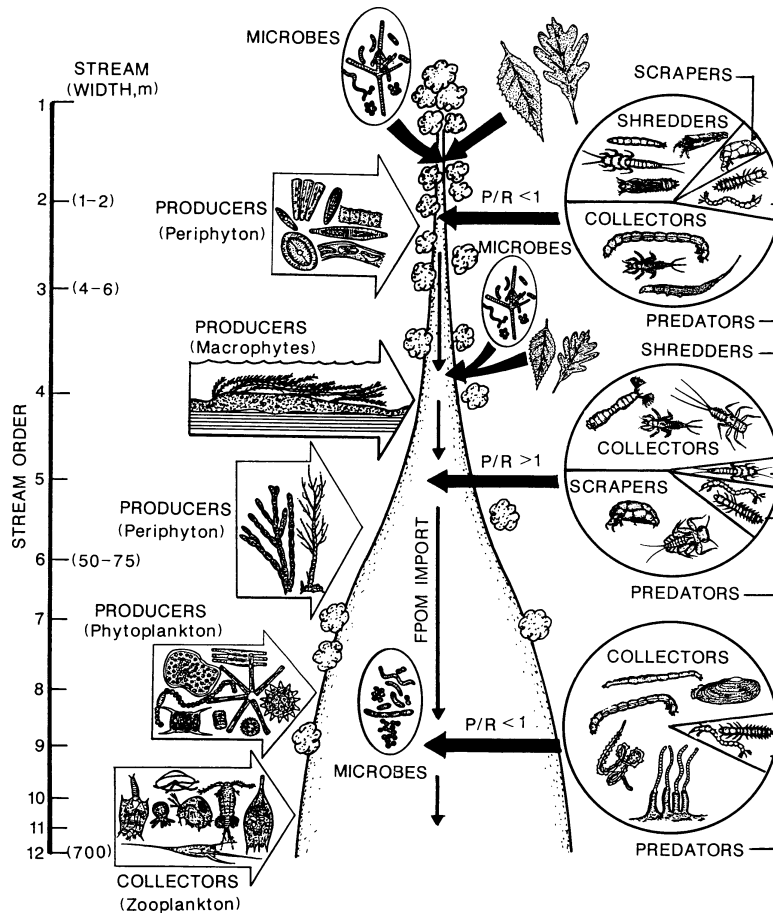
Leaf litter falling into the stream from riparian vegetation is conditioned by microbes, fungi, and eventually provides food for aquatic insects and other invertebrates. These aquatic invertebrates form the food source for juvenile salmon and other stream vertebrates, including trout, sticklebacks, sculpins, tailed frogs, and salamanders. Terrestrial invertebrates falling from the riparian vegetation also provide an important food source.

The productivity of stream ecosystems is controlled by the availability of leaf litter, light energy, and nutrients such as nitrogen and phosphorus. Stream width increases from the headwaters to the lowland reaches, changing the predominant energy input from leaf litter to light. Narrow streams are usually heavily shaded by the forest, which allows very little light to reach the stream. The forest canopy provides large inputs of leaf litter from riparian trees, shrubs, and herbs. As streams widen downstream, the influence of the riparian vegetation decreases, and more light reaches the stream (Murphy and Meehan 1991).

Streams and rivers in coastal British Columbia are subject to high rainfall, so nutrients are constantly washed downstream from the headwaters to the sea. The upstream migration of spawning salmon replenishes these lost nutrients. The adaptive nature of the semelparous salmon life cycle (i.e., spawn once and die) became apparent once the contribution of decaying parental tissue to nutrient cycles and juvenile production was shown (Donaldson 1967; Bilby et al. 1996). As most salmon growth takes place in the ocean, the upstream migration of adults returns nutrients to the spawning streams. Pacific salmon literally leave their bodies to their offspring as a legacy that improves the survival of the species.

Habitat stability is important to juvenile salmon rearing in streams. The old-growth forest landscape in which salmon evolved contributes large wood for channel structure and leaf litter for energy, ameliorates flood peaks and temperature extremes, holds together the soil and rock of the land, and stabilizes stream channels. Especially important is role of the riparian forest in providing stable over-wintering habitat in the form of fallen trees in the stream and stable bank undercuts (Peters et al. 2000, Murphy and Meehan 1991), because, during winter, fish need to minimize their energy expenditure (Cunjak 1996). Pools develop around wood in streams, providing habitat and cover for the rearing juvenile salmon. In large rivers, fallen trees create side channels and floodplain habitats (Murphy and Meehan 1991). Large wood in streams and rivers provides physical habitat and organic material for salmonids by modifying channel morphology and hydraulics, creating pools, undercut banks, channel complexity, back alcoves, sloughs, and side-channels,

thereby enhancing the diversity of stream habitats and aquatic species (Keller and Swanson 1979, Hicks 1990, Shirvell 1990, Gregory and Davis 1992, Ralph et al. 1994). Without these channel features, juvenile salmon are vulnerable to bed movement and high water velocities that might sweep them out of safe habitat during low temperatures.

Effect of logging on salmon and their habitat

The effects of clear-cut logging must be viewed against a background of natural processes in the Pacific Northwest that are unpredictable and occasionally catastrophic. Droughts, floods, debris avalanches and debris torrents, windthrow, and wildfire are all part of the natural environment (Swanston 1991). However, timber harvest increases the frequency of disturbance (Reeves et al. 1995), and can combine the effects of vegetation loss on a wide scale with increased flood severity, rendering large parts of the landscape more vulnerable to the effects of these floods (Chamberlin et al. 1991). The effects of forestry on fish may be divided into timber harvest and regrowth phases (Figure 3-2).

Figure 3-2
Primary effects of timber harvest and forest regrowth on salmon habitat in streams.
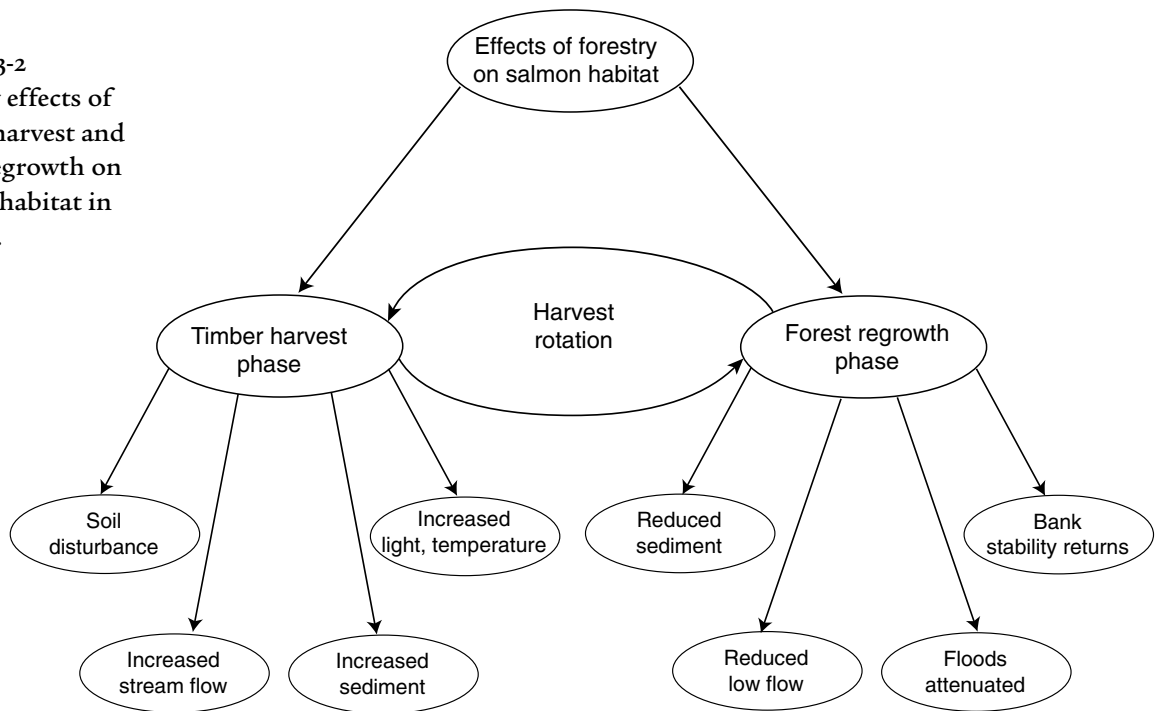
During the harvest phase, the water balance of a basin is changed by clear-cut logging. The immediate response to vegetation removal is increased runoff, both in times of flood and under low flow conditions, because removal of the forest trees during harvest reduces water loss through evapotranspiration, which increases water yield. Flood flows can be increased by timber harvest, especially in areas where rain-on-snow generates peak flows. Snow pack is greater in clear-cut areas than in forested areas, resulting in greater stream flow during thaw (Chamberlin et al. 1991).

Summer low flows are also increased by timber harvest, at least in the short term. In small watersheds (60-101 ha) in the Oregon Cascade Mountains, low flows in August increased about 160% for about 8 years after the start of logging. However, following this period of increased flows was a 19-year period during which the August stream flow was 25% less than that predicted from the control watershed (Figure 3-3; Hicks et al. 1991a). Annual water yields increased 9-16% following clear-cutting of a 12-ha sub-basin of Carnation Creek; summer stream flow increased by 78%, and storm flows increased about 20% (Hartman et al. 1996). In larger basins, the response is less clear, usually because a relatively small fraction of the basin is logged at any one time (Hartman et al. 1996; Buttle and Metcalfe 2000).

Figure 3-3
Water yield in August before and after logging in the western Oregon Cascade Mountains in (A) a clear-cut watershed and (B) a patch-cut watershed. Observed minus predicted water yield refers to the increase or deficit in the total water yield in August compared to the unlogged control (Watershed 2).

Source: Hicks et al. (1991a). Reprinted with permission of American Water Resources Association.
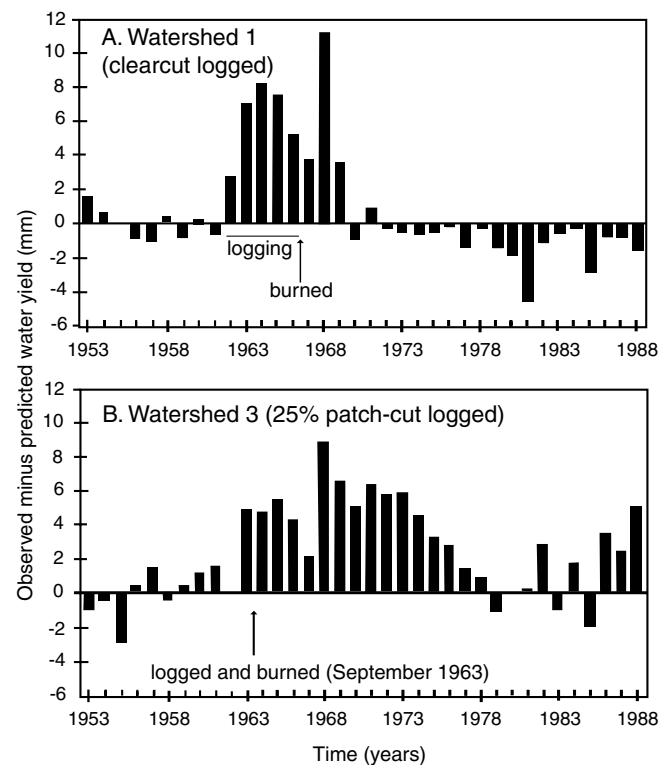
Also during the harvest phase, the soil surface is exposed to rainfall, which results in fine sediment inputs to streams. Fine sediment (sands and silts) can enter streams from clear-cut areas immediately after logging (Everest et al. 1987a).

The effect of fine sediment in spawning streams while eggs and alevins (yolk-sac fry) are in the redds is to clog the spaces between the gravels that the incubating eggs rely on for transport of oxygen-carrying water. Fry can be entombed in the gravels, and fine sediment also consolidates gravel, making redd excavation impossible for spawning salmon. Studies in British Columbia (Scrivener and Brownlee 1989), Oregon (Hall et al. 1987), and Idaho (Stowell et al. 1983) have shown declines in survival to emergence or in salmonid abundance associated with sediment increases after logging. On Haida Gwaii (the Queen Charlotte Islands), increased sedimentation occurred in the lower stream reaches, reducing egg to fry survival of pink and chum salmon. Coho salmon were also affected; logging caused a 15-20% decline in egg-to-fry survival (Tripp and Poulin 1986b).

Road building associated with timber harvest can have a variety of effects on salmon habitat, including increased mass wasting (ie slope failures, landslides), altered streamflow, and barriers to migration. In addition, culverts that are poorly designed, installed, or maintained prevent upstream migration of adults.

During the forest regrowth phase that follows timber harvest is a period when the landscape is particularly vulnerable to mass wasting, landslides, debris torrents, and debris avalanches. Forest vegetation has the effect of binding soils and the underlying parent material, and reducing overland flow, pipe flow through the soil, and waterlogging. The balance between sediment supply, storage, and transport is a key determinant of the integrity of stream habitat. Forested areas generally have limited erosion and mass wasting, and rates of sediment delivery to the stream channel are generally in balance with sediment transport rates (Figure 3-4A).

Once the forest is harvested, the root systems begin to decay and lose strength. In coastal British Columbia, Douglas fir roots lost 50% of their tensile strength within five years after cutting (O'Loughlin 1972). It may take 15 years for forest regrowth to regenerate 50% of the soil stabilization supplied by the old-growth forest, and 26 years until soil strength returns fully (Zeimer 1981). Between the time of root decay and re-establishment of root strength in the regrowing forest, the landscape is vulnerable to mass wasting as a result of intense rainfall. Coarse sediment (gravel and cobbles) can enter streams as a result of timber harvest, but usually does so 5-25 years after removal of the forest cover.

FIGURE 3-4
Stream channels in or near Carnation Creek on Vancouver Island in August 1993.

A. Control stream adjacent to Carnation Creek;

B. Deep bar of gravel in Carnation Creek;

C. Cobbles and gravels from a debris torrent filling a tributary of the Sarita River
PHOTOS: Brendan Hicks

The increased rates of mobilization of soil and coarse material that frequently follow timber harvest deliver more gravel and cobbles to the stream than it can transport, resulting in channels that are choked with large amounts of stored gravel. A classic example was the 1964 flood in the Willamette River, Oregon, which occurred after extensive logging in the basin in the 1950s. This centennial flood carried gravels and cobbles from the headwalls high in the basin to lower gradient reaches downstream. The conclusion from this study, based on analysis of aerial photographs taken in 1967, was that landslides occurred 23-27 times more frequently in clearcuts or near roads than in forested areas (Lyon and Beschta 1983). Carnation Creek also had large

amounts of gravel in the stream channel following logging (Figure 3-4B). However, by 1996 the steep headwater areas logged after 1987 had still not been exposed to storm events with >7-year return period (Hartman et al. 1996), so sediment yield from hillslopes could accelerate rapidly in a large storm.

In extreme cases, mass wasting can yield so much gravel and cobble substrate that the stream's transport capacity is overwhelmed, and the stream ceases to flow above ground, disappearing instead into a matrix of rock (Figure 3-4C). On Haida Gwaii, the overall affect of logging was to accelerate the frequency of landslides by a factor of 34. Fifty percent or more of the drainage basin areas was classified as steepland with slopes $\geq 20°$, or 36% (Rood 1984). Stream channels overwhelmed with coarse sediment from logging had less pool habitat and more riffles. In 1% gradient streams, the area of pool habitat was reduced from about 45% to 15% and riffle area was doubled from about 30% to 60% in mass wasted reaches compared to reaches without mass wasting (Tripp and Poulin 1986a). As stream gradient increased, these effects were less severe. Debris torrents also caused egg losses due to scouring that were estimated at up to 65, 50, and 30% for pink, chum, and coho salmon respectively. Survival to emergence from egg to fry for chum and coho salmon declined in the Carnation Creek watershed to about half their prelogging values (Hartman and Scrivener 1990).

Spawning patterns of salmon in mountain streams of the Pacific Northwest appear to be adapted to the depth and timing of channel bed scour (Montgomery et al. 1999). For chum salmon, egg burial depths were related to the local conditions of scour, and mass spawning reduced scour by coarsening the surface gravels. Thus there is a possible feed-back loop whereby a reduction in the density of spawning chum salmon renders the redds more susceptible to scour, and thus reduces egg-to-fry survival (Montgomery et al. 1996).

Forest trees and shrubs in the riparian zone create shade that reduces light inputs but also minimizes temperature fluctuations. In Oregon, the diel stream temperature range in summer under forest canopy was about 1°C, but was up to 15°C where overstory vegetation was completely removed (Brown and Krygier 1967). Mean monthly maximum temperatures increased 3-8°C in the Coast Range and Cascade Mountains of Oregon (Beschta et al. 1987). Maximal stream temperatures occurred earlier after logging, gradually returning to preharvest levels 15 years after logging (Johnson and Jones 2000).

In streams at or near the thermal tolerance of salmon, such increases in water temperature can cause mortality of rearing juveniles, but increased stream temperatures do not always have a negative effect on salmon. If water temperatures are below the metabolic optimum, increased temperatures can improve survival and growth.

Differences in the responses of salmon to their environment throughout their range emphasize the importance of local studies. For British Columbia, the detailed studies at Carnation Creek on Vancouver Island are of critical importance to understanding the effects of logging on salmon in streams of the north and central coasts. This 15-year study of salmon populations before and after logging in a small, coastal watershed has provided a unique window on the complexities of the biological response of salmon to the impacts of timber harvest.

In coastal British Columbia, stream temperatures are frequently below the range for optimum salmon growth, so increases in stream temperature appear at first to be beneficial. In Carnation Creek, increased stream temperatures caused chum salmon fry to emerge from their redds 1-2 months earlier after logging than before logging. Similarly, coho salmon emerged 2 months earlier (Hartman and Scrivener 1990). However, chum salmon migrate straight to the sea after emergence, and the size of the emergent fry was smaller after logging.

Coho salmon generally require 1 or 2 years of stream rearing before outmigration, and the net effect of the earlier emergence of coho salmon was to lengthen the growing season and increase juvenile size at the end of the summer. Larger juveniles survived the winter better than smaller individuals, so larger numbers of age-1 juveniles occurred in the spring after logging than before logging. Age-1 juvenile coho salmon were also larger after logging than before.

The larger, more numerous age-1 juvenile coho salmon after logging changed the ratio of age-1 smolts to age-2 smolts. Before logging, the numbers of age-1 and age-2 smolts leaving Carnation Creek in the spring were about equal. After logging, age-1 smolts were about three times more numerous than age-2 smolts. In response to the earlier emergence and longer growing season after logging, juveniles were larger; most were large enough to undergo the smolt transformation at age 1 instead of age 2, and thus few remained in the stream for a second winter (Holtby 1988).

The total number of smolts leaving Carnation Creek in the post-logging period from 1976 to 1983 increased by 76% . However, the number of returning adult coho salmon did not match the increase in outmigrant smolts, probably because of the earlier outmigration after logging and the smaller size of smolts. Compared to pre-logging, ocean survival was reduced after harvest because of the smaller smolt size and because the smolts reached the ocean before conditions for survival were optimum (Hartman and Scrivener 1990). The salutory lesson is that the timing of spawning and incubation period for coho salmon was uniquely adapted for water

temperature conditions in the unlogged Carnation Creek, which has also been observed in coho salmon (Konecki et al. 1995) and sockeye salmon in Washington (Hendry et al. 1998). Chum and pink salmon in coastal British Columbia also show unique adaptations to individual river systems (Beacham and Murray 1987; Beacham et al. 1988). After logging, the survival to adulthood of the Carnation Creek coho salmon stock was undermined by the increases in the thermal regime caused by logging, to which the salmon were not adapted.

One suggested mechanism of the observed decrease in ocean survival of coho and chinook salmon is damage by UV-B to the metabolic machinery (Walters and Ward 1998). If this claim has any substance, then riparian forest provides protection for salmon in rearing streams from such damage, and the removal of riparian shade would increase radiation damage.

Large wood in streams is an important feature of salmon habitat. Coho salmon require the slow-flowing water that is characteristic of pools and ponds, and wood creates scour pools. Pool density was a good predictor of coho salmon smolt densities in western Washington (Sharma and Hilborn 2001). In coastal British Columbia, juvenile coho salmon occurred at their highest densities in pools, and 50% of pools were formed by scour associated with large wood (Rosenfeld et al. 2000). The presence of large wood in streams is especially important for over-winter survival of salmon. Winter densities of coho salmon were positively related to wood volumes in streams in south-eastern Alaska (Murphy et al. 1984) and in coastal Washington (Quinn and Peterson 1996). The amount of large wood in streams declines rapidly with the removal of old-growth forest, and large wood from second growth forest is smaller, more mobile, and decays faster than wood from old growth forests (McHenry et al. 1998; Hyatt and Naiman 2001). In the absence of large wood, Haida Gwaii streams contained few hydraulic controls required to store sediments and stabilize bed movements (Tripp and Poulin 1986b). Reaches with large wood stored twice the amount of organic matter as reaches without large wood. (Trotter 1990).

Riparian protection

The impacts of clear-cut logging can be reduced by appropriate protection of riparian vegetation left unlogged as buffer zones. In the Pacific Northwest, recent geologic uplift, weathered rocks and soil, and heavy rainfall contribute to high landslide frequency and high sediment loads because of the widespread occurrence of steep, unstable slopes. Hillslope steepness is one of the simplest indicators of areas prone to debris slides and flows following logging

in British Columbia (Howes 1987). Regions such as the Siuslaw National Forest in the Oregon coast range have extensive areas with slopes steeper than 50%, or 27° (FEMAT 1993). In a modeled basin (Augusta Creek) in the Oregon coast range, up to 50% of the basin needed to be in riparian reserve to maintain slope stability in the steepest headwall areas. (FEMAT 1993).

Forest clearance, whether by timber harvest or wildfire, increases the likelihood of mass erosion (Rieman and Clayton 1997). In steep, erosive terrain, headwalls and swales at the very start of a stream network are the source of rock and debris that can form debris torrents in periods of high rainfall (FEMAT 1993). Such channels, though they may carry only intermittent flow, require the protection of root strength from trees to prevent channel scouring and deposition of large amounts of sediment lower down the basin. The zone of greatest influence of root strength is within half a tree crown diameter, which translates to about 0.3 times tree height, or 15 m (Figure 3-5). The average height of old-growth trees on low-elevation sites of British Columbia is about 50 m.
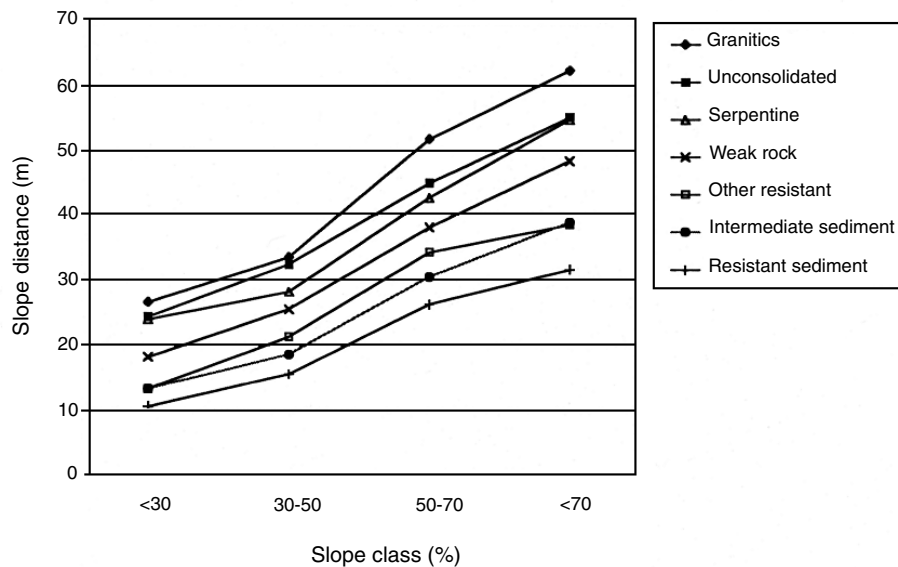
**FIGURE 3-5
Effects of riparian forest on streams as a function of buffer width.**
Source: FEMAT 1993, pV-27.
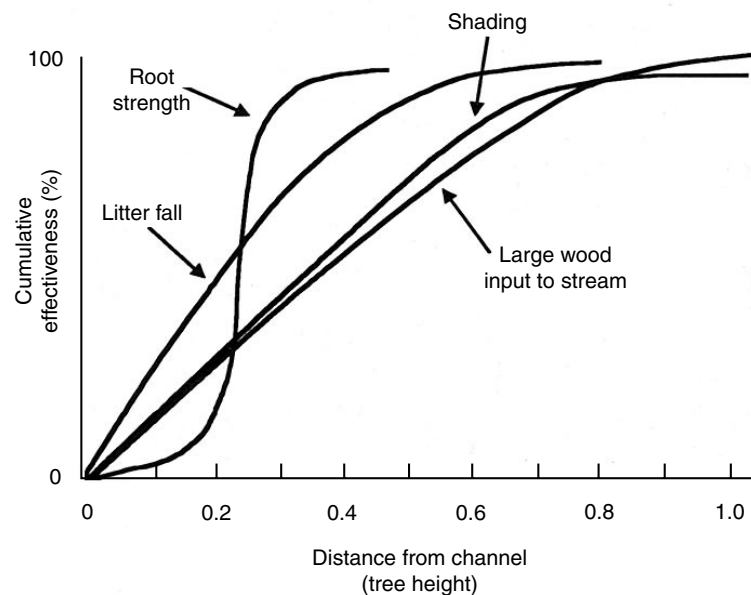
To maintain habitat integrity, intermittent channels require protection just as much as the salmon-bearing reaches. In Carnation Creek, Hartman et al. (1996) considered that the hillslopes required stabilization following logging in the steep headwater areas as part of the options for restoration. However, it is preferable to retain riparian forest to prevent slope failure rather than to

restore it after the event, and as the average land slope of the central coast of British Columbia is 48%, or 26° (Pojar et al. 1999), large areas of individual drainage basins are inappropriate for clear-cut logging. Areas underlain by granite abound in the central coast, and are particularly susceptible to mass wasting (Figure 3-6). The organic soils overlying bedrock that are common in the western portion of the Hecate Lowlands are notoriously unstable (Pojar et al. 1999). The risk of slope failure and mass wasting following logging is severe in much of the coastal forest of British Columbia, and thus maintenance of riparian vegetation within a slope distance of 30-50 m around intermittent streams and steep headwalls at the most upstream parts, is advisable (Figure 3-6).

FIGURE 3-6
Width of riparian buffers required for intermittent streams on different ground slopes and rock types to prevent debris flows and to provide large wood for fish-bearing reaches down-stream.
After: FEMAT 1993, pV-38.

Riparian zones are also an important source of wood, and the most important zone of influence is within one tree height, or about 50 m, of the stream channel (Figure 3-5). The influence of shading is within the same zone, but the primary source of leaf litter is from trees within about 0.6 of a tree height, or about 30 m, from the stream (Figure 3-5).

Conclusions

Forests in coastal British Columbia provide the same protection for salmon and their spawning and rearing habitats in streams and rivers as they do throughout the Pacific Northwest. On a landscape scale, the principal functions of riparian forests in the ecosystem are to:

1) hold the soil and underlying rock together, controlling rates of sediment input,

2) provide a source of large, fallen trees that create channel structure and in-stream cover;

3) provide a continued source of energy through leaf litter inputs to which the stream food webs are adapted; and

4) provide the thermal regimes to which the timing of spawning, duration of egg incubation, and speed of growth of salmon in freshwater is adapted.

Without mature riparian forest adjacent to a significant proportion of the stream network, from salmon-bearing streams and rivers to the steepest headwalls that carry water only intermittently, the stream channel system may become overwhelmed with coarse and fine sediment. Coarse sediment can inundate channel structures, and combined with a loss of large wood and leaf litter inputs, the habitat quality and food web will be seriously undermined, reducing the carrying capacity of streams in summer, and reducing overwinter survival of salmon. Fine sediments compact spawning gravels and smother incubating eggs and the salmon's invertebrate food. Provision of a riparian buffer 30-50 m wide around all parts of the drainage network is important to prevent mass wasting, to provide a source of large wood, and to maintain shading.

The challenge in evaluating the effects of forestry is to determine the magnitude of the link between logging and observed declines in salmon stocks. Competing factors that reduce salmon abundance (i.e., marine conditions, fishing pressure, nutrient returns, and habitat loss in lowlands) make it difficult to isolate the cause behind individual run declines. Forestry is only one influence that can depress salmon stocks. The addition of hatchery fish to streams and rivers also complicates the interpretation of changes in salmon abundance, especially when most of the enhancement efforts are focused on coho and chinook salmon and occur primarily in the logged and developed drainages (Appendix 4).

The hypothesis that the salmon species most reliant on stream rearing (chinook and coho) will be most affected by logging is consistent with the observed run declines, but does not imply causality. Results from Chapter 2

show that between 1950 and 1999 chinook and coho salmon were the species with the highest number of depressed runs, chum salmon were intermediate, and pink salmon (which have minimal reliance on stream rearing) had the least number of depressed runs (Table 3-3).

TABLE 3-3
The status of individual species in indicator streams on the north and central coasts for the decade 1990-1999. Source: Thomson and MacDuffee, this volume.

Species	No. of Systems	Meets Target (%)	Depressed (%)	Very Depressed (%)	Unknown (%)
Sockeye	40	20	22	50	8
Coho	33	15	9	9	67
Pink Even	66	29	40	26	5
Pink Odd	66	29	31	32	8
Chum	49	16	21	57	6
Chinook	27	11	22	56	11

While this observation is consistent with the hypothesis, we note that forestry has not affected all watersheds on the north and central coasts; many indicator and non-indicator systems are still pristine (Figure 3-7). In these unlogged drainages, marine conditions and fishing pressure are the primary influences on salmon abundance.

Preliminary results from 2000 and 2001 show improvement in some coho salmon runs. This recent increase in spawning coho salmon abundance is attributed to drastically reduced fishing pressure since 1998, as well as improved marine survival. The increase in coho salmon abundance since fishing pressure was lifted reinforces the theory that long-term over-fishing seriously depressed the stocks. Though forestry is likely to have reduced coho salmon abundance, the role of over-fishing and marine conditions is evident.

Chum salmon runs on the north and central coasts that have also shown improvement in the last couple of years are believed to be responding to increased marine survival. On the other hand, sockeye salmon have not shown the same recovery and many runs remain very depressed. Preliminary results from chinook salmon returns for 2000 and 2001 still show that very few systems are meeting their spawner targets. While many chinook salmon rivers have been heavily logged, some intact systems are also showing poor returns. Fishing pressure, overly optimistic spawner targets, and marine survival may be additional factors affecting the status of chinook salmon stocks.

In 2000 and 2001, returns of pink salmon, which have the least reliance on freshwater habitat, were very strong in both logged and unlogged systems.

Sixty percent of pink salmon indicator runs met spawner targets in 2001. This is double the number of any other species meeting its spawner target. Pink salmon are the most abundant species on the north and central coasts, lending weight to the importance of a species' life history in determining the role of the freshwater environment.

Figure 3-7
Loss of original forest in coastal watersheds on the north and central coasts. Source: Sierra Club of British Columbia, 2002.
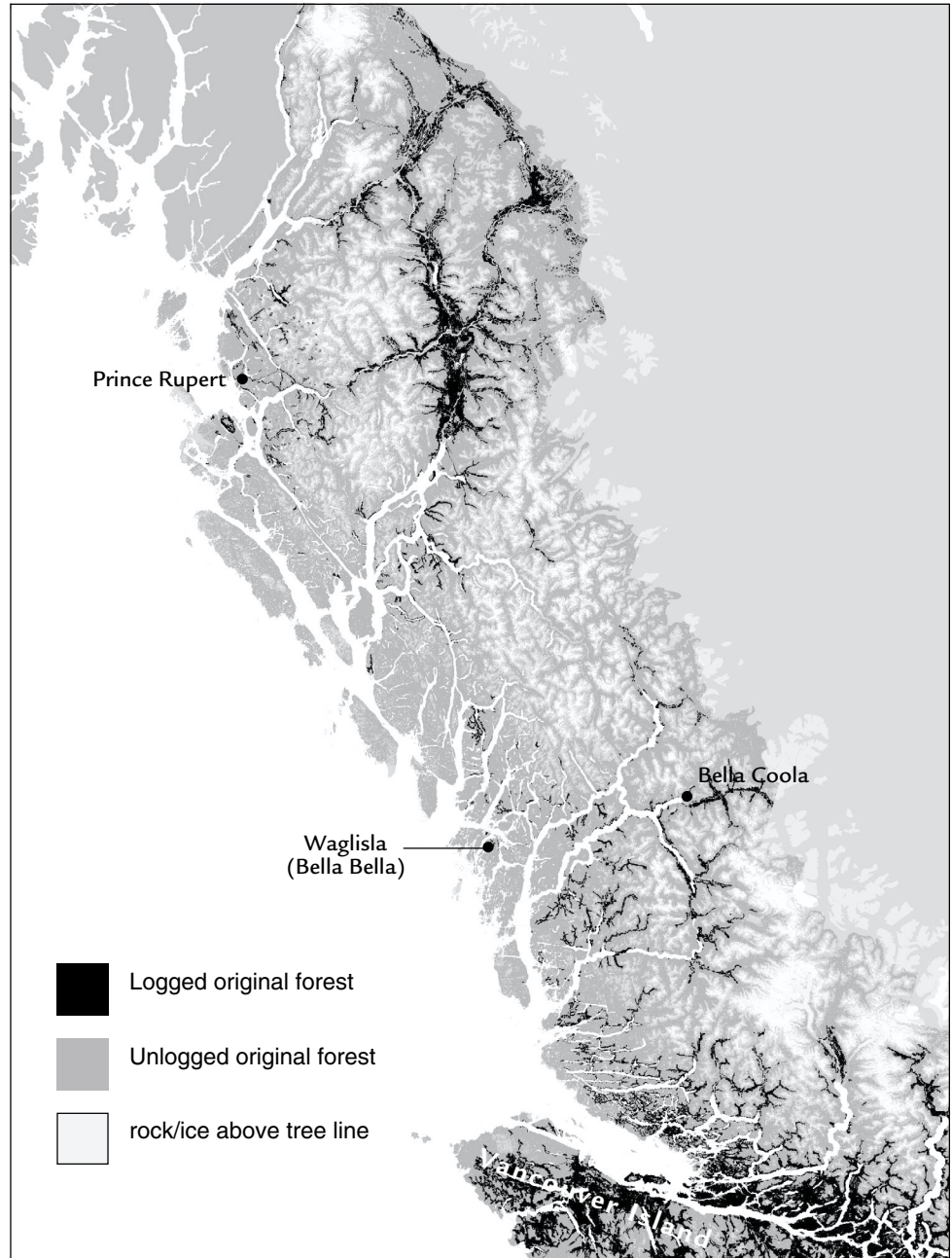
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