Post-harvest Condition of Stream Channels, Fish Habitats, and Adjacent Riparian Areas: Resource Stewardship Monitoring to Evaluate the Effectiveness of Riparian Management 2005-2014

FREP

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Key Messages for Resource Managers:

- Post-harvest monitoring of streams over a 10-year period shows that the percentage of streams in the two top-functioning categories – properly functioning condition (PFC) and functioning at risk (FR) – was 68% in the Forest Practices Code (FPC) era, 66% in the transition era, and 67% in the *Forest and Range Practices Act* era. These outcomes did not vary significantly from the FPC to the FRPA eras.
- Stream reaches in the two top functioning categories reflect forest practices that have achieved riparian management objectives under FRPA.
- Four out of five streams that were deemed not properly functioning (NPF) were small, non-fish bearing streams (class S6, 71%) and the smallest fish-bearing streams (class S4, 16%).
- Streams with the best outcomes occurred where the retention of overstorey trees were managed for windthrow; there was little or no disturbance to the stream bed, banks, and adjacent riparian area; and fine sediments from road construction and maintenance were managed.

1.0 INTRODUCTION

Forest and range resource management is a complex process that involves balancing ecological, social and economic considerations. The key purpose of this extension note is to inform resource management professionals of the biophysical outcomes of management practices on riparian and stream function. This information will help enhance the knowledge on which professional advice, decisions and accountability are based, and assist with sound decision making.

From 2005 to 2014, under the Forest and Range Evaluation Program (FREP), B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development field staff assessed stream and riparian conditions of 2,287 stream reaches in, or adjacent to, randomly selected cutblocks (Figure 1). The sites assessed included 1,071 stream reaches where forest harvesting occurred entirely under the *Forest Practices Code of British Columbia Act* (FPC; 1996-2003),

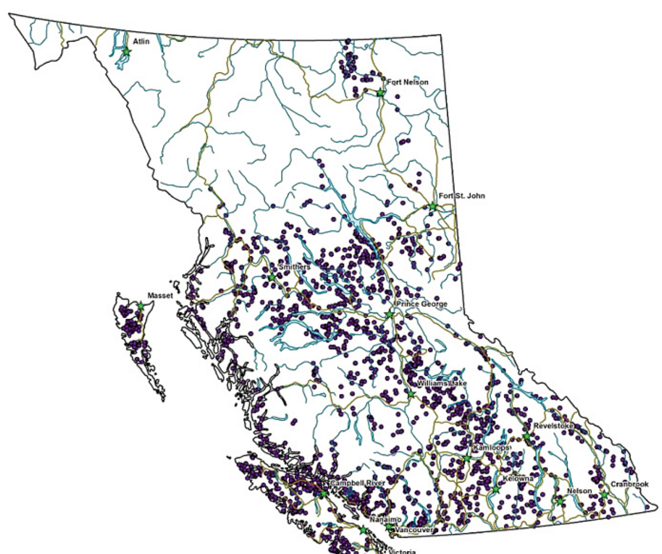

Figure 1. *Location of riparian sample sites representing forest harvesting under the FPC (1996–2003), transition (2004-2006), and FRPA (2007-2014) eras combined.*

FREP Mission:
Collect and communicate the best available natural resource monitoring information to inform decision making, improve resource management outcomes and provide evidence of government's commitment to environmental sustainability. http://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/integrated-resource-monitoring/forest-range-evaluation-program

British Columbia

630 reaches where harvesting occurred during the transition era (2004-2006) between the relatively prescriptive FPC and the current *Forest and Range Practices Act* (FRPA), and 586 sites harvested fully under FRPA (2007-2014), which accommodates more flexible, licensee-driven forest practices. The objectives of these assessments were to determine whether forest and range practices have been effective in maintaining the ecological function of streams and the adjacent riparian areas (Tschaplinski 2010, 2011), and whether differences in riparian management outcomes were discernible among these three management eras.

2.0 EVALUATION QUESTIONS AND INDICATOR THRESHOLDS

Resource Stewardship Monitoring (RSM) for streams and riparian areas is based on a checklist of 15 questions, each representing a principal indicator of individual stream channel and riparian conditions (Tripp et al. 2009). The questions and the attributes and functions they address are unchanged from the methodology previously employed to assess sites managed under the FPC (Tschaplinski 2010, 2011). Both biological and physical characteristics and processes of the stream environment and adjacent riparian area are addressed by the RSM checklist and protocol (Tschaplinski and Brownie 2010).

The riparian assessment requires a *yes* (pass), *no* (fail), or *not applicable* (NA) answer to each of the 15 questions. For most streams, nine of 15 questions require multiple *no* answers to a specific indicator before the question can also be answered *no*. Thresholds used for all indicators of acceptable stream and riparian condition represent 75-95% of the values typically recorded on streams undisturbed by humans. Conditions that exceed the thresholds indicate conditions beyond the normal range exhibited by streams undisturbed by humans. The assessment, by design, avoids comparing streams to an "average" or "ideal" undisturbed condition (Tripp 2013).

Depending on channel morphology, substrate conditions, and fish use, there are between 114 and 120 measurements, estimates and observations required to complete a stream-riparian assessment, based on 38-60 specific indicators covered by checklist statements that support the main checklist questions. Each assessment includes measurements of channel width, depth and gradient, as well as vegetation retention in the riparian area.

3.0 DETERMINING FUNCTIONING CONDITION

Each stream was deemed to be in one of four possible outcomes based on the number of *no* responses to the 15 evaluation questions:

(1) properly functioning condition (PFC); 0-2 *no* responses

(2) functioning at risk (FR); 3-4 *no* responses

(3) functioning at high risk (FHR); 5-6 *no* responses; and

(4) not properly functioning (NPF); > 6 *no* responses.

The PFC and FR outcomes equate respectively to the "very low" and "low" impact ratings used in FREP Multiple Resource Value Assessments (MRVA) reports (http://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/integrated-resource-monitoring/forest-range-evaluation-program/frep-multiple-resource-value-assessments) and Assistant Deputy Minister Resource Stewardship reports (B.C. Ministry of Forests, Lands and Natural Resource Operations 2012, 2013, 2015, 2016). The top two outcomes most closely meet the objectives for riparian management as stated in both the FPC and the *Forest Planning and Practices Regulation* (Section 8) of FRPA. Trends in outcomes within and among stream classes, forest management eras, and administrative areas were analyzed statistically by Chi Square (χ^2).

4.0 SAMPLE STREAM REACHES

The province-wide sample of assessed stream reaches covered all six riparian management classes (S1-S6) (Table 1).

Table 1. *Number of stream reaches assessed for post-harvest riparian and stream channel conditions from 2005 to 2014 for each riparian class. This sample represents cutblocks harvested from 1996 to 2013. Fish habitat conditions were also assessed in the fish-bearing stream classes (S1, S2, S3 and S4). Management eras are defined by year of harvest completion.*

FOREST MANAGEMENT ERA	RIPARIAN CLASS (S1–S6) WITH STREAM WIDTH (m)						TOTAL
	FISH-BEARING				WITHOUT FISH		
	S1 > 20 m	S2 > 5 to ≤ 20 m	S3 1.5 to ≤ 5 m	S4 < 1.5 m	S5 > 3 m	S6 ≤ 3 m	
Forest Practices Code 1996 – 2003	3	54	230	210	63	511	1,071
Transition 2004 – 2006	5	42	121	100	48	314	630
Forest and Range Practices Act 2007 – 2014	1	41	132	70	56	286	586
ALL	**9**	**137**	**483**	**380**	**167**	**1,111**	**2,287**

Sample sites were categorized depending on their location in the province and are represented here as "north", "south" and "Coast," with the boundary between north and south defined at the Cariboo-Chilcotin resource district. The relative number of streams sampled for each class varied among geographic areas. Class S6 streams in north, south and Coast areas made up 40, 52 and 57% of the total stream sample in each area, respectively. The Coast area had conspicuously fewer S4 streams (5.5%) compared with 16 and 25% in the south and north areas, respectively, and more S5 streams (17%) compared with other areas (3-4%).

5.0 RESULTS

Post-harvest monitoring over 10 years shows that, throughout the province, about two-thirds of all stream reaches assessed in each forest management era were in the two top categories of properly functioning condition (PFC) and functioning at risk (FR) (Figure 2). These streams with PFC and FR outcomes reflect forest practices that have achieved riparian management objectives under both the FPC and FRPA. Other sites scored in the functioning at high risk (FHR) and not properly functioning (NPF) categories. Twelve percent were deemed NPF in each era. Streams in the top two categories declined from 68% in the FPC era to 66 and 67% in the transition and FRPA eras, respectively. These changes were not significant (Prob. $\geq \chi^2$: all $p \geq 0.35$). Similarly, FHR and NPF outcomes combined did not differ significantly among forest management eras and ranged between 32-34% (Prob. $\geq \chi^2$: all $p \geq 0.35$).

However, the increase in PFC outcomes from 38% to 42% between the FPC and FRPA eras was significant (Figure 2; Prob. $\geq \chi^2$: 0.04). Correspondingly, the percentage of assessed sites included within the three impact categories combined (FR, FHR and NPF) declined significantly from 62 to 58% between the same eras and between pre-FRPA years (FPC plus transition) and FRPA eras (Prob. $\geq \chi^2$: $p = 0.04$). In this respect, there appears to be a measure of improvement in post-harvest outcomes in the total population of assessed stream reaches. However, FPC era cutblocks were 5.6 years old on average at the time of assessment – older on average than either transition era (3.3 years) or FRPA era (2.3 years) cutblocks. Therefore, FPC era sites were exposed to the stresses of three additional winters (ANOVA, $p < 0.001$) compared to FRPA era sites, a factor that may have affected outcomes (i.e. potentially led to increased levels of impact).

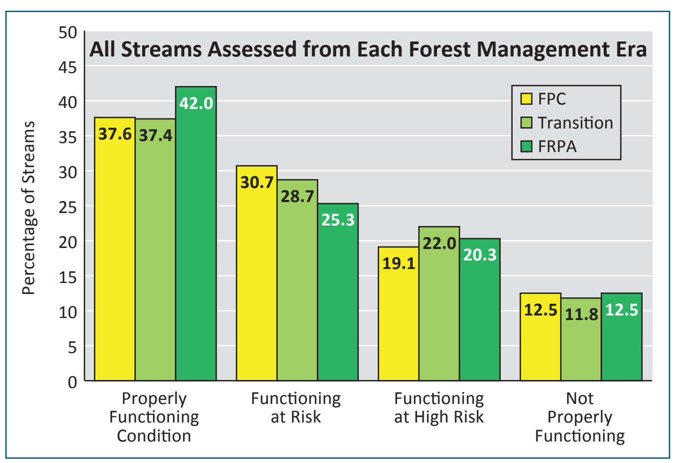

Figure 2. *Post-harvest outcomes of riparian management assessed under the Forest and Range Evaluation Program for streams managed during the FPC (1996-2003), transition (2004-2006), and FRPA (2007-2014) eras.*

No other province-wide trend in any of the four outcome categories either individually or in combination was statistically significant among the forest management eras for all assessed sites combined (Prob. ≥ χ^2: p = 0.08 – 0.94).

For all forest management eras combined, 71% of the 282 sites deemed NPF were small, non-fish-bearing S6 streams in headwater areas, followed by the smallest fish-bearing S4 streams at 16% (Figure 3). Seven percent of all NPF stream reaches were fish-bearing S3 streams and 5% were non-fish-bearing S5 streams (Figure 3). When results for stream reaches classified as fish bearing are considered alone (all eras combined), 78% of the 1,009 S1–S4 streams were found to have limited to no observable impacts (PFC+FR), while 22% were assessed as FHR and NPF combined. Seven percent were deemed NPF and most of those were S4 streams. The highest frequencies of the two top outcomes were observed for fish-bearing streams provided with mandatory riparian reserves. Provincially, 84% of 629 S1, S2 and S3 streams combined were in the two top post-harvest categories, and 4% were deemed NPF. Assessed streams in the two top outcomes were 83% in the FPC era, 82% during the transition era, and increased to 87% in the FRPA era. The increment from the pre-FRPA to the FRPA eras is significant (Prob. ≥ χ^2: ≤ 0.04).

Post-harvest outcomes have improved for S3 streams in the FRPA era compared with pre-FRPA years as shown by the percentage of NPF stream reaches, which decreased by two-thirds from 5-6% to < 2%, and FHR+NPF reaches, which decreased by nearly one-half to 11% (Table 2; Prob. ≥ χ^2: ≤ 0.05). However, outcomes for non-fish-bearing S5 streams trended in the opposite direction, with NPF reaches increasing from 6 and 4% in the pre-FRPA eras to 12% during the FRPA era. Similarly, S5 streams in the two poorest outcomes (FHR+NPF) increased from 22 and 19% in the FPC and transition eras, respectively, to more than 32% in the FRPA era (Table 2; Prob. ≥ χ^2: ≤ 0.05).

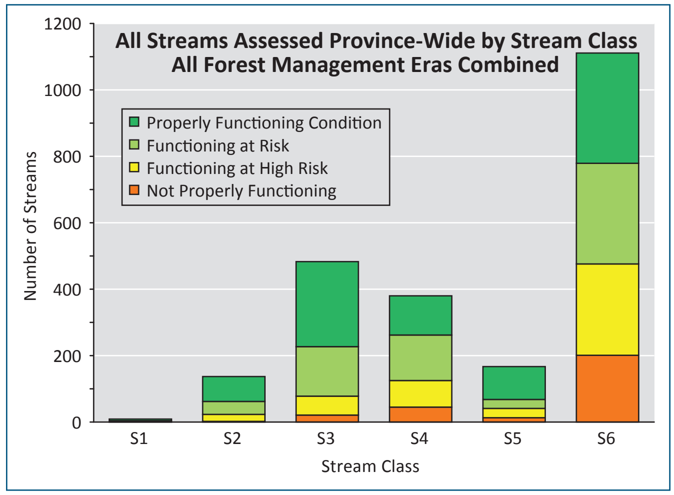

Figure 3. *Province-wide results of post-harvest condition assessments for the six riparian stream classes for all forest management eras combined.*

Of nine class S1 reaches, five were scored PFC, three FR, and one FHR (sample (n) = 2,287 stream reaches). Other trends among eras were not statistically significant; for example, the decline in the percentage of NPF reaches for all fish-bearing stream classes combined from 7-8% in the pre-FRPA eras to < 5% in the FRPA era, and the corresponding decline in FHR+NPF outcomes from 23-24% to 20% (Table 2; Prob. ≥ χ^2: > 0.05).

The outcomes for some stream classes varied little among forest management eras. In particular, S6 non-fish-bearing streams in the two poorest assessment outcomes (FHR and NPF) varied from 42 to 45% among eras, while the percentage of S6 stream NPF outcomes ranged between 15 and 18% (Table 2).

Table 2. *Comparison of the percentages of stream reaches in the two best (PFC+FR), two poorest (FHR+NPF), and NPF post-harvest outcomes province-wide for fish-bearing and non-fish-bearing streams among the three forest management eras in B.C. since 1996.*

RIPARIAN CLASS		FPC ERA (1996-2003)			TRANSITION ERA (2004-2006)			FRPA ERA (2007-2014)		
		PFC+FR	FHR + NPF	NPF	PFC+FR	FHR + NPF	NPF	PFC+FR	FHR + NPF	NPF
Fish-Bearing	**S1**	100	0	0	80.0	20.0	0	100	0	0
	S2	82.4	17.6	1.8	87.2	12.8	0	80.5	19.5	2.4
	S3	83.2	16.8	5.2	79.8	20.2	5.9	88.6	11.4	1.5
	S4	69.1	30.9	10.7	66.6	33.3	13.5	61.4	38.6	12.9
	ALL	**77.3**	**22.7**	**7.1**	**76.1**	**23.9**	**7.7**	**79.5**	**20.5**	**4.9**
Without Fish	**S5**	78.1	21.9	6.3	80.8	19.2	4.3	67.9	32.1	12.5
	S6	58.4	41.6	18.6	55.4	44.6	16.5	56.6	43.4	18.9
	ALL	**60.6**	**39.4**	**17.2**	**58.9**	**41.1**	**14.9**	**58.5**	**41.5**	**17.8**

Table 3. *Summary of stream-riparian condition assessments conducted in the coastal and Interior geographic areas of the province (Coast, north and south areas).*

GEOGRAPHIC AREA	FOREST MANAGEMENT ERA	SAMPLE (n)	POST-HARVEST STREAM-RIPARIAN CONDITION (PERCENT OF ASSESSED STREAM REACHES)			
			PFC	FR	FHR	NPF
Coast	**FPC**	231	34.2	22.5	25.5	17.7
	Transition	178	32.0	26.4	23.6	18.0
	FRPA	188	35.6	23.9	21.8	18.6
	ALL	**597**	**34.0**	**24.1**	**23.8**	**18.1**
North	**FPC**	469	33.7	36.5	19.0	10.9
	Transition	181	30.9	37.0	20.4	11.6
	FRPA	238	46.2	29.8	13.4	10.5
	ALL	**888**	**36.5**	**34.8**	**17.8**	**10.9**
South	**FPC**	392	44.4	28.6	15.6	11.5
	Transition	250	46.0	24.4	22.0	7.6
	FRPA	160	43.1	20.0	28.8	8.1
	ALL	**802**	**40.4**	**25.6**	**20.2**	**9.6**

Regional differences in stream-riparian functional outcomes reported previously for annual surveys conducted between 2005 and 2008 (Tschaplinski 2010, 2011) were reflected in the present results for the Coast, north and south areas (Table 3).

Higher percentages of NPF outcomes occurred in the Coast area (18-19%) compared to the two Interior areas (8-12%) across all forest management eras and assessed streams. This regional difference likely reflects management challenges associated with operations in the steeper terrain and higher precipitation regimes typical of coastal watersheds. It may also reflect varying levels of riparian tree retention along small streams among regions.

Few distinct patterns are apparent among the three areas or within each area among forest management eras. Only minor variations in outcomes among forest management eras was shown in the Coast. However, PFC outcomes in the northern Interior increased from 31-34% in the pre-FRPA eras to 46% in the FRPA era. Correspondingly, the percentages in the FR and FHR outcomes declined in the north (Table 3).

The southern Interior has shown a progressive decline in NPF outcomes from 12 to 8% from the FPC to the FRPA eras. However, this trend is opposed by a progressive increase in FHR outcomes from 16 to 29% over the same time frame (Table 3).

The percentage of streams in the two top post-harvest categories combined (PFC+FR) were generally higher in the Interior than on the Coast (Table 3); however, few other trends were apparent. In the southern Interior, PFC+FR outcomes declined from 72 to 63% from the FPC to the FRPA era, while the same categories on the Coast increased marginally from 57 to 60% (Table 3). The decline in PFC and FR outcomes in the southern Interior appears to be made up of more streams that scored in the FHR category. In the northern Interior, the percentage of streams in the top two post-harvest categories increased from 70 to 74% from the FPC to FRPA eras.

5.1 BROAD CAUSAL FACTORS

As reported previously (Tschaplinski 2011), streams that were assessed with the best outcomes (PFC and FR) most frequently occurred in harvest areas where: streamside retention consisted of overstorey trees managed for windthrow risk; there was little or no disturbance to the stream bed, banks and adjacent riparian area; and fine sediments at road stream crossings were managed.

Summed over all forest management eras, logging was the most common cause of all impacts in each geographic area of the province, particularly in the Coast area where it was the main factor in 71% of the *no* answers to the 15 main protocol questions (Table 4). Logging was less of a dominant factor in the south and north Interior areas, although still the leading cause, accounting for 42% of impacts (Table 4).

Table 4. *Province-wide summary of the percent of no answers to the 15 main protocol questions caused by broadly defined activities or factors at all sites assessed under FREP from 2005 to 2014 (n=2,287). Numbers in parentheses are the mean numbers of no answers per site attributed to each cause.*

IMPACT ACTIVITY OR FACTOR	GEOGRAPHIC AREA			
	COAST	NORTH	SOUTH	ALL
Logging (tree harvesting)	71 (2.8)	42 (1.5)	42 (1.4)	**50** (1.8)
Natural factors	14 (0.6)	37 (1.3)	30 (1.0)	**28** (1.0)
Roads	9 (0.3)	13 (0.5)	12 (0.4)	**11** (0.4)
Livestock (cattle)	0 (0.0)	0 (0.0)	7 (0.2)	**3** (0.1)
Upstream factors	4 (0.2)	8 (0.3)	8 (0.2)	**7** (0.2)
Other, human-related	1 (0.1)	1 (<0.1)	1 (<0.1)	**1** (<0.1)
All	100 (4.0)	100 (3.5)	100 (3.3)	**100** (3.6)

Provincially, logging accounted for one-half of the impacts recorded in riparian assessments. Other forestry-linked impacts included roads, which caused on average 11% of the *no* answers, with small differences among geographic areas (Table 4). Livestock (cattle) were a notable problem specific to the south Interior area, where it caused 7% of the *no* answers, primarily in the Cariboo and Thompson-Okanagan regions, and parts of the Kootenay-Boundary Region. Other human-related impacts included effects on streams by various public roads, powerline or pipeline right-of-way clearings, and recreation trails (mainly for all-terrain vehicle use). Upstream factors were mostly recorded in the field as unknown (e.g., unknown sediment sources), but were otherwise similar to impacts originating on-site within the sample reaches or in adjacent riparian areas.

Throughout British Columbia, natural factors (events or conditions) were the second most-common cause of *no* answers after logging, particularly in the north area where it accounted for 37% of the *no* answers. The effects of natural factors on the outcomes of the riparian assessments was highest in the north and south areas, adding 1.0 and 1.3 *no* answers on average per assessed site, respectively. In the Coast area, 0.6 *no* answers were added on average at each site. When naturally caused *no* answers are factored out, the number of *no* answers left in the north and south areas (2.3-2.2) were considerably lower than in the Coast area (3.4).

5.2 SPECIFIC CAUSAL FACTORS

Falling and yarding, windthrow, and low riparian retention were the three greatest specific problems relating to logging in all geographic areas, accounting for most of the *no* answers and almost all of the logging-related impacts (Table 5). Falling and yarding and low retention were responsible for 53% of the impacts in the Coast area, with windthrow contributing an additional 12% of the impacts.

Falling and yarding and low retention caused fewer impacts in both the south and north areas (22 and 23%, respectively), while windthrow contributed to 17 and 16% of the impacts, respectively. Impacts due to old (pre-1995) logging made up 3% of the impacts in the Coast area and 2% throughout the province. Other factors each contributed ≤ 1% of the impacts province-wide.

Table 5. *Percentage of no answers caused by specific factors on FREP riparian assessments conducted from 2005 to 2014. Shading identifies specific impact sources that accounted for 4% or more of all no answers on riparian assessments.*

SPECIFIC FACTORS CAUSING IMPACTS		COAST	NORTH	SOUTH	ALL
Logging	Falling and yarding	36	11	11	18
	Windthrow	12	16	17	15
	Low riparian tree retention	17	12	11	13
	Old (previous) logging	3	1	1	2
	Machine disturbance, harvesting	2	1	1	1
	Slides/sloughs	2	0	0	1
	Water courses diverted	1	0	0	< 1
Roads	Road surface erosion-related issues	4	7	6	6
	Ditch/fill/cut slope erosion issues	4	5	5	5
	Culvert issues	0	1	1	1
Livestock	Trampling	0	0	7	2
	Excessive grazing/browsing	0	0	1	< 1
Natural	High natural background sediments	3	12	9	8
	Wind	4	8	6	6
	Torrents	4	3	4	4
	Organic stream bed	1	3	2	2
	Floods	0	3	2	2
	Beetle kills	0	2	3	2
	Slides/sloughs (mass wasting)	2	1	1	1
	Stream dammed (by beavers)	0	2	1	1
	Fire	0	0	2	1
	Excessive browsing (beavers, ungulates)	0	0	1	< 1
	Trampling (ungulates)	0	1	1	1

Natural conditions or disturbances were collectively the second most-common cause of all *no* answers in all areas (Table 5). High background levels of fine sediments were dominant in the Interior, ranging from 9% in the south to 12% in the north, followed by wind (6 and 8%, respectively). Wind and torrents were the leading causal factors on the Coast (4% each), followed by fine sediments (3%). Mass wasting contributed 2% of the impacts in the Coast and 1% elsewhere. Organic stream beds, floods, and beetle kills each made up ≤ 1% of the impacts on the Coast, increasing to 2-3% in the Interior areas, and 2% province-wide. In general, a wider range of natural impacts were recorded for north and south area streams compared to the Coast. In addition to naturally high background sediments, wind and torrents in the Interior regions, impacts were also attributed to organic stream beds, floods and beetle kills (2-3% each), beavers (1-2%), fire (2% in the south), mass wasting (1% each), and ungulates (1% each). Ungulate related impacts were primarily due to trampling along streambanks and the adjacent riparian area.

After logging and natural impacts, roads were the next most frequent cause of impacts in all three areas, varying from 8 to 13% totalled for all road-related factors by geographic area (Table 5). The main specific causes were evenly divided between road surface erosion and the erosion noted along the adjacent ditches and on both cut and fill slopes. Culverts (primarily blockages to fish movement upstream, or sediment and woody debris movement downstream) were a comparatively small problem.

5.3 SITE-LEVEL FORESTRY VS. OTHER EFFECTS

Impacts from sources not related to site-level forestry practices resulted in 1.0 *no* answer on average for all streams and forest management eras combined (Table 6). This average varied little among forest management eras (from 0.9 *no* responses per site in the FPC era to 1.1 afterward). Site-level forestry practices added 2.6 *no* responses per affected stream reach on average for all years combined (Table 6). The frequency of site-level forestry impacts also changed little among management eras,

Table 6. *Relative effects of forestry-related (cutblock or site level) practices and other effects (non-cutblock-related) on stream-riparian conditions by stream class and forest management era (n = 2,287).*

STREAM CLASS	MEAN NUMBER OF NO RESPONSES TO 15 MAIN INDICATOR QUESTIONS							
	FPC ERA (1996-2003)		TRANSITION ERA (2004-2006)		FRPA ERA (2007-2014)		ALL ERAS	
	SITE-LEVEL FORESTRY	OTHER	SITE-LEVEL FORESTRY	OTHER	SITE-LEVEL FORESTRY	OTHER	SITE-LEVEL FORESTRY	OTHER
S1	1.0	1.3	0.4	2.4	0	1.0	0.6	1.9
S2	1.0	1.7	0.7	1.6	0.8	1.8	0.8	1.7
S3	1.5	1.2	1.3	1.7	1.2	1.2	1.4	1.3
S4	2.7	1.1	2.1	1.6	2.5	1.4	2.5	1.3
S5	1.9	0.8	1.7	0.7	1.8	1.4	1.8	1.0
S6	3.5	0.6	3.4	0.8	3.4	0.8	3.4	0.7
All	**2.7**	**0.9**	**2.4**	**1.1**	**2.5**	**1.1**	**2.6**	**1.0**

declining from an average of 2.7 *no* responses per assessed site in the FPC era to 2.4 and 2.5 in the transition and FRPA eras, respectively. Over all eras, site-level forestry impacts were more frequent on S4, S5 and S6 streams compared to fish-bearing S1, S2 and S3 streams buffered with riparian reserves (Table 6). In contrast, impacts not related to site-level forestry always exceeded forestry impacts for S1 and S2 streams in any era. The effects of the two sources of impact were generally similar for S3 streams, with site-level forestry impacts exceeding other effects by a small margin in the FPC era and all eras combined. Larger streams generally found in the lower portions of watersheds demonstrated the cumulative effects of forestry and non-forestry related activities in all eras.

Little variation was observed in the mean numbers of site-level forestry impacts within each stream class among forest management eras; however, there was significant variation among geographic areas. The Coast showed fewer non-forestry-related *no* answers (0.9 per assessed site) and a greater level of forestry-related *no* answers (3.1 per site) compared to the north and south areas where non-forestry-related impacts were 1.7 and 1.8 per site, respectively, while site-level forestry contributed 1.7 and 1.5 *no* answers, respectively.

5.4 RIPARIAN TREE RETENTION

Measurements of riparian retention showed that all six stream classes were frequently managed by leaving buffers. Both the percentage of streams buffered and the width of buffers were similar from the FPC to the FRPA eras. Class S1, S2 and S3 fish-bearing streams, which require mandatory riparian reserves of 50, 30 and 20 m wide, respectively, were provided (on average) with buffers of retained vegetation equivalent to 82, 53 and 35 m wide, respectively. Class S1 streams were always adjacent to cutblocks because of their large size. The location of class S2 and S3 streams, whether adjacent or within cutblocks had little effect on buffer width. Class S2 streams either within or adjacent to cutblocks had buffers 53 m wide on average, while Class S3 streams within vs. adjacent to cutblocks had buffers 32 m and 35 m wide, respectively.

Class S4, S5 and S6 streams have no mandatory retention requirement in regulation. However, when buffers were used, these stream classes in the 10-year FREP sample had buffer widths equivalent on average to unharvested strips 21, 26 and 10 m wide, respectively. These streams were frequently buffered by “avoidance”, i.e., locating the cutblock boundary to be entirely or partly outside of the riparian management area (RMA). Alternatively, a buffer was provided when the streams were located within cutblocks. Considerable variation between these two strategies occurred between the Coast and north and south areas (Table 7).

Table 7. *Number of streams sampled in or beside cutblocks and the percentage of streams with buffers at least 5 m wide by geographic area and stream class, assessed from 2005 to 2014. Buffer width on streams located within a cutblock was the average width of the buffer on both sides of the stream, while buffer width on streams adjacent to a cutblock was the average width of the buffer on the side closest to the cutblock.*

STREAM CLASS	LOCATION RELATIVE TO CUTBLOCK	NUMBER OF STREAMS				PERCENT WITH RIPARIAN BUFFERS			
		COAST	NORTH	SOUTH	ALL	COAST	NORTH	SOUTH	ALL
S1	Adjacent	3	4	2	9	100	100	100	100
	Within	0	0	0	0	No data	No data	No data	No data
S2	Adjacent	43	41	44	128	100	95	100	98
	Within	2	4	3	9	100	100	100	100
S3	Adjacent	55	185	154	394	96	100	99	99
	Within	15	42	20	77	100	98	90	96
S4	Adjacent	11	123	91	225	100	89	92	91
	Within	21	91	35	147	48	48	77	55
S5	Adjacent	64	18	26	108	91	100	88	92
	Within	37	12	9	58	73	58	44	66
S6	Adjacent	71	91	190	352	96	89	77	84
	Within	267	258	227	752	19	34	32	28
All	Adjacent	247	462	507	1216	96	95	89	93
	Within	342	407	294	1043	30	45	42	39

In general, relatively more S4 and S6 streams were located adjacent to cutblocks in the south and north areas compared to the Coast, especially in the south where a dryer climate and lower stream density may make this a more feasible option. The percentage of in-block S6 streams that were buffered also tended to be higher in the north and south areas (32-34%) compared to 19% on the Coast (Table 7).

Retention strategies around S4, S5 and S6 streams varied, and location relative to the cutblock appeared to be a main factor influencing the frequency of buffers (Table 7) and overall retention levels (i.e., buffer widths; Table 8). For the Coast, north and south areas, and province-wide, buffer use and mean buffer width was greater for streams located adjacent to the cutblock compared to those within cutblocks (Table 8; Student's t-test, all $p < 0.05$). Correspondingly, the lower average buffer widths of in-block streams had in all cases but two (south area S4 streams and north area S5 streams where in-block and adjacent stream buffers were similar) an average of 1.2 to 2.6 more *no* answers to indicator questions than streams adjacent to cutblocks, depending on geographic area and stream class (Table 8).

Table 8. *Buffer widths (m) for class S4, S5 and S6 streams located adjacent to cutblocks versus within cutblocks, and the average number of no answers to the main indicator questions by stream class and location.*

STREAM CLASS	LOCATION RELATIVE TO CUTBLOCK	AVERAGE BUFFER WIDTH (m)				AVERAGE NUMBER OF NO ANSWERS			
		COAST	NORTH	SOUTH	ALL	COAST	NORTH	SOUTH	ALL
S4	Adjacent	21.5	23.5	24.4	23.8	3.0	3.4	3.3	3.4
	Within	14.2	13.6	19.0	15.2	5.1	4.6	3.4	4.4
S5	Adjacent	30.4	34.1	24.6	29.7	2.4	2.9	2.1	2.4
	Within	16.8	26.1	10.6	18.0	4.1	2.8	4.1	3.8
S6	Adjacent	23.6	21.8	15.9	19.1	2.8	2.9	2.9	2.9
	Within	3.0	7.9	8.1	6.1	5.4	4.1	4.6	4.7

The levels of tree retention adjacent to S4 streams was consistent with the findings reported earlier for FREP effectiveness monitoring (Tschaplinski 2011) and in the post-harvest study of these streams in the British Columbia central Interior in 2000 (Chatwin et al. 2001). However, higher retention levels on S4 streams in the FREP samples did not always translate into increased protection or better post-harvest outcomes. Despite significantly higher overall retention levels on S4 streams that were located within blocks, the number of *no* answers for these streams did not differ appreciably from S6 streams also within cutblocks (Table 8). For streams outside the cutblocks, the outcomes on S4 streams were poorer than for S6 streams. These S4 streams were possibly more affected by upstream factors than S6 streams because of channel morphology, that is, more sensitive to disturbance from upstream sources or fish passage requirements at road-stream crossings. Neither effects would be mitigated by higher retention levels.

The presence of buffers on S5 streams equivalent on average to no-harvest strips 26 m wide shows that these relatively large, non-fish-bearing streams were generally managed with retention levels approaching those applied to S3 fish-bearing streams. With 76% of class S5 stream reaches in the two top functioning condition outcomes (PFC and FR), 59% in the PFC category, it appears that the management strategy for these streams has been effective.

Stream avoidance by several methods was a common approach for protecting small streams. Not only did forest licensees frequently configure harvest areas to exclude much or all of the RMAs of adjacent streams, wildlife tree patches were often included within the RMAs of small streams for the dual purpose of stream channel protection and achieving wildlife and biodiversity objectives. A third common approach was to leave no-harvest buffers 10 m wide on S4 streams, a "best management practice" recommendation from the *Riparian Management Area Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995).

Although riparian buffers were commonly left along small streams, low riparian tree retention was the most frequently cited cause of impacts to stream characteristics and function, responsible for 13% of all *no* answers to the protocol questions for all assessments. This included a number of S2 and S3 streams where mandatory reserves were left in place, but low retention in the outer management zone of the RMAs contributed to excessive windthrow in the inner reserve zone. On streams without reserves, impacts associated with low retention were primarily attributed to reduced large woody debris supply to streams, falling and yarding (especially for S6s), and significant changes to the composition of the riparian vegetation.

Impacts due to falling and yarding are directly linked to low riparian retention. Other effects associated with low retention include alterations to the channel bed, stream banks, woody debris processes, and connectivity. Impacts related to low retention and falling and yarding combined accounted for 31% of all *no* answers on the assessments, ranging from 22 and 23% in the south and north areas, respectively, to 53% on the Coast (Table 5).

The highest frequency of NPF outcomes and the lowest frequency of PFC outcomes occurred in S4 and S6 reaches without a riparian buffer. Stream reaches (all riparian classes combined) in the best category of properly functioning condition had the widest buffers followed sequentially by those in FR, FHR and NPF. Stream reaches receiving buffers in the 6-10 m width category had significantly better post-harvest functional outcomes than streams with harvesting to the banks. Samples are now sufficiently large to show significantly and progressively improved functional outcomes for buffers of increasing width: 11-20 m, 21-30 m, and >30 m, respectively. Streams provided with the widest buffers showed the highest frequencies of top post-harvest outcomes.

The results show that buffers at least 10 m wide appear to provide useful levels of protection for stream-riparian function, but wider buffers, such as the riparian reserves on the larger fish-bearing streams, provide a higher level of stream-riparian protection for a number of attributes and processes, including a reduced risk of windthrow. With narrow buffers, many advantages gained with increased retention and fewer falling and yarding issues can be negated by impacts due to increased windthrow. FREP assessments do not measure harvest-related alterations to water temperature, riparian microclimate, and aquatic primary production. However, FREP results appear to be consistent with the growing body of experimental research that has shown that changes in these conditions can be detected where harvesting has occurred 30 m or more from the stream bank (Richardson et al. 2002, 2005; Kiffney et al. 2003).

6.0 OPPORTUNITIES FOR IMPROVED MANAGEMENT OF RIPARIAN/FISH RESOURCE VALUES

The results of site-level riparian-stream monitoring continue to show both positive results and areas for potential improvement. Four main factors can influence the success of stream and riparian management:

1. Level of RMA tree retention;
2. Windthrow;
3. Falling and yarding trees across streams; and
4. Road-associated generation and transport of fine sediments.

Most assessed streams deemed NPF are non-fish-bearing S6 streams, with some in the fish-bearing class S4. More than other stream classes, class S6 and S4 streams are strongly affected by: (1) low RMA tree retention, and (2) falling and yarding across streams. Excessive stream sediment affects four indicator questions directly, and low RMA tree retention directly affects another three. By managing sediment and providing for more tree retention along priority small streams:

1. The majority of post-harvest outcomes (50-75%) could fall in the PFC category, with 90-95% in the combined PFC+FR categories;
2. FHR outcomes could be reduced to 5-10%; and
3. NPF outcomes could be reduced to 5% or less.

These outcomes can be achieved by retaining more wind-firm vegetation more frequently around class S4 streams and priority S6 streams, minimizing the introduction of logging slash, and minimizing fine sediment delivery to channels from roads and stream crossings throughout the entire road life cycle. Substantial RMA retention already occurs on some S4, S5 and S6 streams. However, nearly 15% of S4s and S5s, and 45% of S6s assessed by FREP are provided with little or no tree retention. Without further increasing riparian retention levels within a watershed or landscape, this existing level of retention could be distributed where the greatest benefits for fish and aquatic values would be achieved with minimum additional cost. Accordingly, the following levels of retention could be considered to achieve improved outcomes for priority S4 and S6 streams in particular:

1. Establish full wind-firm buffers 10 m wide on all lower gradient (<10%) perennial class S4 fish-bearing streams and all perennial non-fish-bearing class S5s and S6s that deliver water, alluvial sediments, nutrients, organic materials, and invertebrates to fish-bearing habitats and (or) drinking water sources downstream.
2. Retain, at a minimum, all non-merchantable trees, understory trees, smaller vegetation, and as many wind-firm trees as possible within the first 10 m of the RMA for all other S4 streams and for S5 and S6 streams (e.g., intermittent and ephemeral streams with low transport capability) directly connected to fish-bearing areas and (or) drinking water sources (B.C. Ministry of Forests, Lands and Natural Resource Operations 2012).

When conducting forestry activities in close proximity to streams, further substantial improvements to outcomes can be made by:

1. Avoiding physical contact with stream banks and streambeds when falling and yarding around class S6 streams; fall and yard trees away from the channel wherever possible;
2. Minimizing the introduction of logging-related woody debris into the channels (leaving natural debris in place); and
3. Minimizing sediment introductions from roads and ditches during construction, maintenance, logging, and deactivation.

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For more information on FREP, please see: http://www.for.gov.bc.ca/hfp/frep/index.htm.

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