EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms **45**, 1974–1989 (2020)

Published online 15 April 2020 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/esp.4859

Decadal-scale changes in suspended wood after riparian recruitment in managed stands in headwater streams of coastal British Columbia, Canada

Felipe Rossetti de Paula,[1,3]* John S. Richardson,[1] Alex C.Y. Yeung,[1] Stephen J. Mitchell[1] and Devesh Bahuguna[2]
[1] Department of Forest & Conservation Sciences, University of British Columbia, Vancouver, BC Canada
[2] Strategic Natural Resource Consultants Inc., Port McNeill, BC Canada
[3] Department of Forest Sciences, "Luiz de Queiroz" College of Agriculture, University of São Paulo, Piracicaba, SP Brazil

Received 6 June 2019; Revised 11 March 2020; Accepted 13 March 2020

*Correspondence to: Felipe Rossetti de Paula, Department of Forest Sciences, "Luiz de Queiroz" College of Agriculture, University of São Paulo, Av. Pádua Dias, 11, CP 9, Piracicaba, SP, 13418-900, Brazil. E-mail: ferossetti@gmail.com

ESPL
Earth Surface Processes and Landforms

ABSTRACT: Large wood (LW) affects several ecological and hydrogeomorphic processes in streams. The main source of LW is riparian trees falling inside channels. However, in confined valley floors, falling trees are more likely to be suspended above the channel. Eventually, these suspended trees will decompose and break to finally fall into the channel to better provide functions for streams. We evaluated changes in wood decay, length, diameter, and suspended status (suspended or non-suspended) 17 years post-harvest and nine years after the first sampling occurred in 2006 in 12 headwater streams of coastal British Columbia, Canada. We also evaluated whether changes differed among riparian management treatments (no-harvest buffers of 10 and 30 m in width, thinning, and unharvested reference sites), and identified the factors affecting wood changes and suspended status. Wood pieces advanced in decay, became shorter, and 34% of them (n = 108) changed status from suspended to non-suspended. Non-suspended wood pieces were more decayed and shorter than suspended wood. Suspended wood was longer, thicker, less decayed, and represented 46.5% (n = 147) of the wood sampled in 2006. Our findings revealed limited influences of riparian management on many aspects of wood changes considered in this study. Changes in wood characteristics were more likely for pieces that were smaller in diameter, longer, and suspended closer to the water. The transition from suspended to non-suspended LW can be a long-term process that can increase wood residence time and reduce LW in-stream functions particularly in confined stream valleys. The suspended stage is also an important mechanism underlying time lags in stream ecosystem responses to riparian tree fall. © 2020 John Wiley & Sons, Ltd.

KEYWORDS: wood decay; wood breakage; suspended wood; habitat structure; riparian management; stream ecology

INTRODUCTION

The recruitment of large wood (LW – usually defined as pieces of wood ≥ 1 m in length and ≥ 10 cm in diameter; Bilby and Bisson, 1998) is an important ecological process for maintaining the structure and functioning of streams. LW provides food and cover for invertebrates and fishes (Boss and Richardson, 2002; Eggert and Wallace, 2007; Lujan *et al.,* 2011; Valente-Neto *et al.,* 2015), traps sediments, organic matter, and nutrients in the stream reach (Warren *et al.,* 2007; Flores *et al.,* 2011; Elosegi *et al.,* 2017; Parker *et al.,* 2017). LW also affects channel–floodplain dynamics (Naiman *et al.,* 2010) and changes stream morphology by creating pools and cascades that add physical complexity to the aquatic habitat (Rosenfeld and Huato, 2003; Paula *et al.,* 2011; Elosegi *et al.,* 2017). Riparian forests are an important source of LW to the channel, especially from tree mortality, bank erosion, and windthrow (McDade *et al.,* 1990; Benda and Sias, 2003; Hassan *et al.,* 2005; Lassetre *et al.,* 2008; Bahuguna *et al.,* 2010). However, given the geometry of small stream valleys in the Pacific Northwest, it is more likely that trees longer than channel width will not enter the channel immediately after tree fall. Instead, they tend to stay suspended above the channel in 'bridge' positions (*sensu* Wohl *et al.,* 2010) for years or decades (Hassan *et al.,* 2005; Bahuguna *et al.,* 2010; Jones *et al.,* 2011; Bahuguna *et al.,* 2012), where they have less influence on stream ecological and hydrogeomorphic processes compared to in-stream logs (Richmond and Fausch, 1995; Jones *et al.,* 2011).

To change in status from being suspended above the channel to touching the stream bed, wood pieces generally have to experience biochemical decomposition and mechanical breakage, which modify their integrity (i.e. wood density; Bilby *et al.,* 1999; Chen *et al.,* 2005; Fraver *et al.,* 2013) and physical characteristics (i.e. length, diameter, branch complexity; Tanaka and Yagisawa, 2009;Merten *et al.,* 2013 ; Iroumé *et al.,* 2017), respectively. These changes make LW more susceptible to falling into the channel, where they can touch the stream bed and interact more effectively with stream processes (Jones *et al.,* 2011). In general, tree size (length and diameter) is an important feature that affects wood changes; studies have shown that breakage and decomposition were more likely for pieces of wood that were longer and thinner in diameter (Merten *et al.,* 2013; Iroumé *et al.,* 2017). Also, other important factors that influence wood change include wood density of different tree species (hardwood versus softwood), and stream morphology and hydrology (Hassan *et al.,* 2005; Cadol and Wohl, 2010; Merten *et al.,* 2010; Wohl *et al.,* 2012; Fraver *et al.,* 2013; Ruiz-Villanueva *et al.,* 2016a).

Riparian management strategies are implemented in order to reduce the negative impacts of harvesting and to promote the long-term sustainability of riparian vegetation and stream conservation in managed landscapes (Richardson *et al.,* 2012; Sibley *et al.,* 2012; Ring *et al.,* 2017). The most common riparian management strategy is the implementation of riparian forested buffers (Richardson *et al.,* 2012) that can have varying width and logging intensity depending on local regulations (Lee *et al.,* 2004; Richardson *et al.,* 2012; Cristan *et al.,* 2016; Ring *et al.,* 2017). Recently, logging through riparian thinning (removal of a prescribed amount of basal area in the riparian zone) has been used in North America in order to emulate natural and periodic disturbances, such as windthrow and fires, followed by stand regeneration (Blinn and Kilgore, 2001; Kreutzweiser *et al.,* 2012; Sibley *et al.,* 2012). However, these management techniques may be insufficient to protect all ecological processes and habitat features of riparian and stream ecosystems. For example, narrower riparian buffers may increase short term LW inputs to the streams as the remaining riparian trees are more exposed to post-harvest windthrow (Bahuguna *et al.,* 2010; Bahuguna *et al.,* 2012).

Logging-associated changes in forest canopy (such as gap formation after partial harvest and light/advection from opening on either side of the buffer; Brosofske *et al.,* 1997; Braithwaite and Mallik, 2012; Warren *et al.,* 2016) may accelerate stream metabolism by modifying the environmental characteristics that affect the decomposition process (Kiffney *et al.,* 2003; Warren *et al.,* 2016; Bechtold *et al.,* 2017), potentially accelerating changes in suspended wood in these streams. Increases in light input and temperature in the riparian and stream environment are typical responses (e.g. Brosofske *et al.,* 1997; Kiffney *et al.,* 2003; Moore *et al.,* 2005; Braithwaite and Mallik, 2012). These factors, in addition to moisture from the stream surroundings, are known to increase the metabolic rates of microorganisms (Kiffney *et al.,* 2003; Ferreira and Chauvet, 2011; Martins *et al.,* 2017). In streams, microorganisms form a biofilm over LW surfaces, especially fungi and bacteria (Hax and Golladay, 1993; Steinman and Mulholland, 2007). Fungi and bacteria act directly on wood decomposition and changes wood's structural integrity (Diez *et al.,* 2002; Gulis and Suberkropp, 2007). Wood conditioning by microbes make it more accessible to invertebrates that use the wood as habitat or food (Hax and Golladay, 1993; Benke and Wallace, 2003). The foraging activity of grazing macroinvertebrates and fishes on the biofilm assemblages growing over LW surfaces (Hax and Golladay, 1993; Benke and Wallace, 2003; Lujan *et al.,* 2011) can also contribute to wood decay. Although the suspended wood is a suitable resource for terrestrial fauna (Kumar *et al.,* 2018; Chang *et al.,* 2019), aquatic fauna may eventually access this material depending on how distant the log is from water surface during high flows.

Our understanding of LW dynamics (e.g. input, storage, and depletion) has been developed based on investigations of in-stream LW (Benda and Sias, 2003; Warren and Kraft, 2008; Wohl *et al.,* 2012; Merten *et al.,* 2013; Ruiz-Villanueva *et al.,* 2016a; Iroumé *et al.,* 2017; Iroumé *et al.,* 2018). Channel-suspended LW has received much less attention, and in particular, the mechanisms underlying the conversion of suspended LW to non-suspended LW are poorly known, which have important influences on wood storage, depletion, and functions in headwater streams (Ruiz-Villanueva *et al.,* 2016b). Recently, Bahuguna *et al.* (2012) studied the LW conversion from suspended to non-suspended condition using a chronosequence approach, but our study advances our understanding by returning to the same streams to track changes on individual LW pieces over time.

In this work, we studied changes in the characteristics of suspended wood in headwater streams in a temperate, coastal rainforest 17 years post-harvest and also nine years after the first sampling occurred in 2006. We first evaluated changes in wood conditions (decay, length, and diameter) in relation to the conversion of suspended LW to non-suspended LW. Since decay rates and environmental conditions may vary with riparian management practices, we also compared outcomes in unharvested forest, forested buffers of 10 and 30 m in width, and riparian thinning with 50% of basal area logged. Finally, we evaluated which LW characteristics determined previously in 2006 (decay status, total length, base diameter, span length, and height above stream bankfull) and stream physical attributes [bankfull channel width (BCW) and valley floor width (VFW)] best explained the changes in suspended LW. Our hypotheses are: (1) after a decade, wood advanced in decay, became shorter, and changed their status to non-suspended; (2) wood changes were the highest in the management treatments where canopy alterations were the highest (i.e. buffers of 10 m and riparian thinning, followed by buffers of 30 m) in comparison to unharvested forest; (3) suspended wood that was thicker and suspended higher above stream bankfull had low increases in decay and less reduction in length due to reduced exposure to moist and dry conditions and hydraulic forces, respectively, delaying wood fall in the channel. Our findings will advance our understanding about LW dynamics in headwater streams with potential applications in riparian management programs.

METHODS

Study area

We sampled 12 headwater streams (Table 1) located in the Malcolm Knapp Research Forest (MKRF; Figure 1) at the foothills of the Coast Mountains of the Pacific Northwest, approximately 45 km east of Vancouver, British Columbia (Kiffney *et al.,* 2003; Lecerf and Richardson, 2010). Streams were incised, relatively straight, and constrained by hillslopes and narrow fluvial terraces (Bahuguna *et al.,* 2010). Forest cover in the study area was composed of dense, young to mature, conifer-dominated vegetation that naturally regenerated (~84 years of age in 2015) after logging in the early 1900s and wildfire in 1931 (Kiffney *et al.,* 2003; Bahuguna *et al.,* 2010). Stands are mainly composed of western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), Douglas-fir (*Pseudotsuga menziesii*), black cottonwood (*Populus trichocarpa*), and red alder (*Alnus rubra*) (Kiffney *et al.,* 2003; Bahuguna *et al.,* 2010). The study area has a maritime climate with dry and warm summers and wet and cold winters. Total precipitation ranges between 2200 mm and 3000 mm per year, depending on locations within MKRF. Snow is occasional in the area with low elevations (120–450 m). Soils are shallow and originated from glacial till and glacio-marine deposits. The topography varies from flat to hilly and gently rolling, with some bedrock knolls. The underlying geology of

Table 1. Site characteristics for the 12 studied streams

Stream	Riparian forest treatment	Bankfull channel width (m)	Valley floor width (m)	Watershed area (ha)	Elevation (m a.s.l.)	Average stream gradient (%)	Total area of watershed logged (%)	Stream length logged (m)	Canopy openness (%)
Mike	Reference	4.5	10.8	25	240	8	0	0	8.3
EC	Reference	3.3	7.2	44	295	4	0	0	8.0
SC	Reference	4.2	6.6	35	135	4	0	0	9.0
D30	Buffer 30 m	1.6	10.0	43	180	8	22	450	12.5
H30	Buffer 30 m	3.8	23.8	55	205	3	22	300	14.2
SK30	Buffer 30 m	2.7	9.0	19	175	10	20	400	13.5
C10	Buffer 10 m	2.9	11.0	89	110	4	21	335	20.3
F10	Buffer 10 m	2.0	7.1	11	170	14	24	340	21.8
G10	Buffer 10 m	3.4	7.6	84	190	4	23	265	20.3
A50	50% Thinning	2.7	13.8	26	250	5	15	137	18.5
E50	50% Thinning	2.5	11.0	27	370	13	12	283	19.9
F50	50% Thinning	5.1	7.2	38	405	19	6	233	14.2

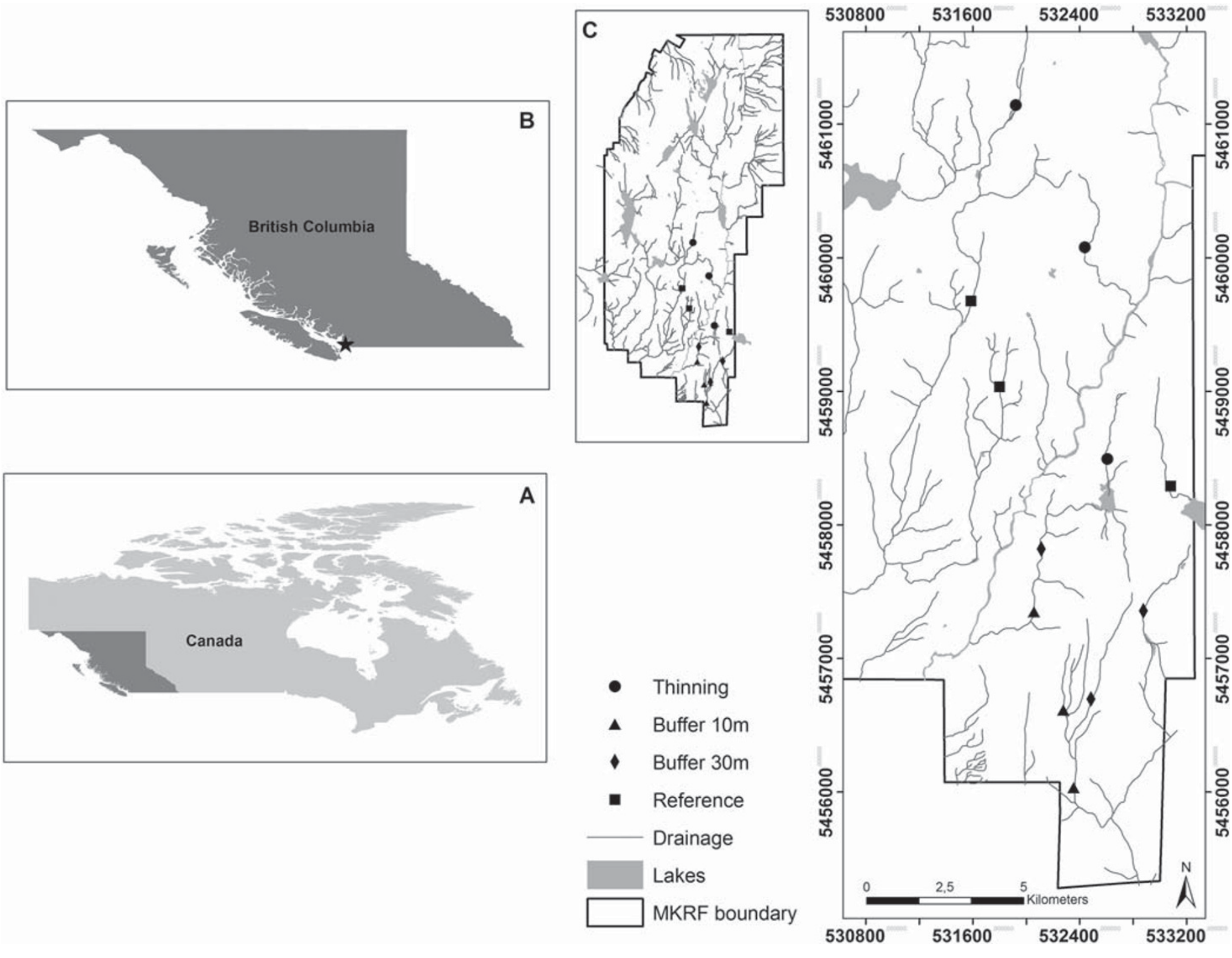

Figure 1. The location of the study area in the province of British Columbia, Canada. In detail (C), the location of the study streams in the Malcolm Knapp Research Forest [MKRF; represented by the star in (B)].

the study area is quartz diorite, diorite, and granodiorite (Bahuguna *et al.,* 2010).

Experimental design and LW sampling

This study was conducted in the same streams included in a larger, integrated study of forest management impacts on small streams in second-growth forests (Kiffney *et al.,* 2003). The variables considered in this study are presented in Table 2. Streams were allocated to one of two buffer width treatments [10 m (abbreviated B10) and 30 m (B30) along each stream margin], a thinned treatment (T50), where 50% of the basal area of trees was cut on upland and riparian area (Richardson *et al.,* 2010), and unharvested reference streams (REF), with three replicates per treatment. Harvesting of experimental manipulations of

Table 2. Description of the variables considered in this study

Variable	Code	Description
Decay class	DECAY	Decay condition of logs based on visual classification (see Table S1 for details; Bartels *et al.,* 1985)
Change in decay classes	DCHANGE	Decay condition in 2015 subtracted from decay condition in 2006. Classes: DC1 – one category change (i.e. decay 1 to decay 2); DC2 – two category change (i.e. decay 1 to 3); DC3 – three category change (i.e. decay 1 to 4); DC4 – four category change (i.e. decay 1 to 5).
Total length (m)	LENGTH	The total length of log measured from base to the top with tape
Decrease in length (m)	BREAK	Change in length of log by subtracting length in 2015 from 2006
Base diameter (cm)	BDIAM	Wood diameter measured at the base with diameter tape
Mid-span diameter (cm)	SPANDIAM	Wood diameter measured at the middle of stream with diameter tape
Top diameter (cm)	TOPDIAM	Wood diameter measured at the top with diameter tape
Change in base diameter (cm)	BCHANGE	Change in base diameter of log by subtracting diameter in 2015 from 2006
Change in top diameter (cm)	TCHANGE	Change in top diameter of log by subtracting diameter in 2015 from 2007
Suspended status	STATUS	Wood status in the stream: suspended (SUSP) and non-suspended (NOSUSP)
Height above stream bankfull (cm)	HABANK	Wood height from bankfull height of stream
Height above stream bed (cm)	HABED	Wood height from stream bed
Span length (m)	SPALEN	Distance between two suspending points of wood
Species	SP	Coniferous: western hemlock (*Tsuga heterophyla*), western redcedar (*Thuja plicata*), sitka spruce (*Picea sitchensis*), Douglas-fir (*Pseudotsuga menziesii*); Deciduous: paper birch (*Betula papyrifera*), red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), black cottonwood (*Populus trichocarpa*)
Tree group	GROUP	Coniferous (CONI) or deciduous (DECI)
Riparian forest treatment	TREAT	Riparian forest treatment (see Table 1)
Bankfull channel width (m)	BCW	Distance across channel at bankfull flow
Valley floor width (m)	VFW	Distance of valley across channel

riparian buffer width took place in 1998, whereas thinning occurred in 2004.

In the summer of 2006, Bahuguna *et al.* (2010) sampled a subset of all suspended logs in these channels to study the effects of riparian buffer management on LW recruitment after windthrow events. The sampled stream reach was 150 m in length, which was identical in length for each riparian experimental unit. Each stream was divided into sub-reaches whenever there was a major change in stream orientation, in channel morphology, or valley form. Two measures of BCW and VFW were taken in each sub-reach. Suspended logs were tagged with uniquely numbered plastic tags, usually near the mid-stream on the downstream side. Logs were classified as suspended if they were elevated above the bankfull height of the stream (e.g. height above stream bankfull $>$ 0 cm; Bahuguna *et al.,* 2010). Those classified as in-channel by Bahuguna *et al.* (2010) were excluded from this study.

To be tagged and measured, downed logs (from adjacent trees in riparian stands (Miquelajauregui, 2008)) needed to be: fallen or windthrown since completion of harvest in 1998, suspended at least part of stream bankfull width, greater than 7.5 cm in diameter at mid channel, and in decay classes 1–3, based on the decay classification system largely used in the Pacific Northwest of the United States (Bartels *et al.,* 1985). In this classification, decay class is based on bark, texture, shape, color of wood, and other criteria, with class 1 being least decayed and class 5 most decayed (see Supporting Information Table S1 for details). Logs were also identified by species (see Table 2). Each log was measured for its total length, span length, base diameter, mid-span diameter, top diameter, height above stream, and bankfull width.

In 2015, nine years after the sampling by Bahuguna *et al.* (2010), we re-measured only the logs that were classified as suspended in the 2006 sampling to study changes of suspended wood. In our study, we classified logs as SUSP [logs suspending and not touching the stream bed (height above stream bed $>$ 0) (Figure 2A) and NOSUSP (loose logs which lay entirely on the stream bed and partial bridge logs in which at least one log ends touch the stream bed; Jones *et al.*, 2011 (Figure 2B)]. Logs not found in 2015 (i.e. missing tags, log burial, decay, and downstream transport) were classified as not found.

To locate the starting point of the experimental reaches, we used previous knowledge of the sites (John Richardson, 2015) and signs in the riparian areas from previous study (Miquelajauregui, 2008). For each log that we found, we measured the total length (base to the tip of the log), the base and top diameter, the height above stream bed, and assigned a decay class using the same decay classification system previously mentioned (but now also including the more advanced decay classes 4 and 5). For logs that broke in two or more pieces, we always considered the piece containing the identification tag. Broken pieces without tag were excluded if they were completely dis-attached from the tagged piece (i.e. only touching). In cases where they were firmly connected to the tagged piece (i.e. residual connections in the trunk between the pieces), they were still considered part of the log. Changes to lower decay classes are unlikely and clearly an error in the classification. When this happened, we kept the decay class assigned in 2006. The exception was changes from decay classes 2 to 1 and 3 to 1 when trees were considered dead in 2006 but were observed to have grown green branches during our sampling. Using these log measures, we calculated decreases in wood length (BREAK), changes in base diameter (BCHANGE) and top diameter (TCHANGE), and decay change (DCHANGE) by subtracting the measures between sampling years.

We made an effort to sample the diameter at the same location of the given log where the initial measure was recorded (in our sampling, we took the measures approximately 10 cm from each log end and we assumed that the first measure was taken somewhere within this 10 cm). If the logs have since shortened due to breakage or decay, then we measured a different point in 2015. We calculated decay change because it provides information on how fast one log changed from the previous decay condition to the new class during the sampling interval (e.g. a large log initially classified as decay class 1 may have decomposed slowly to decay class 2 after nine years, while a

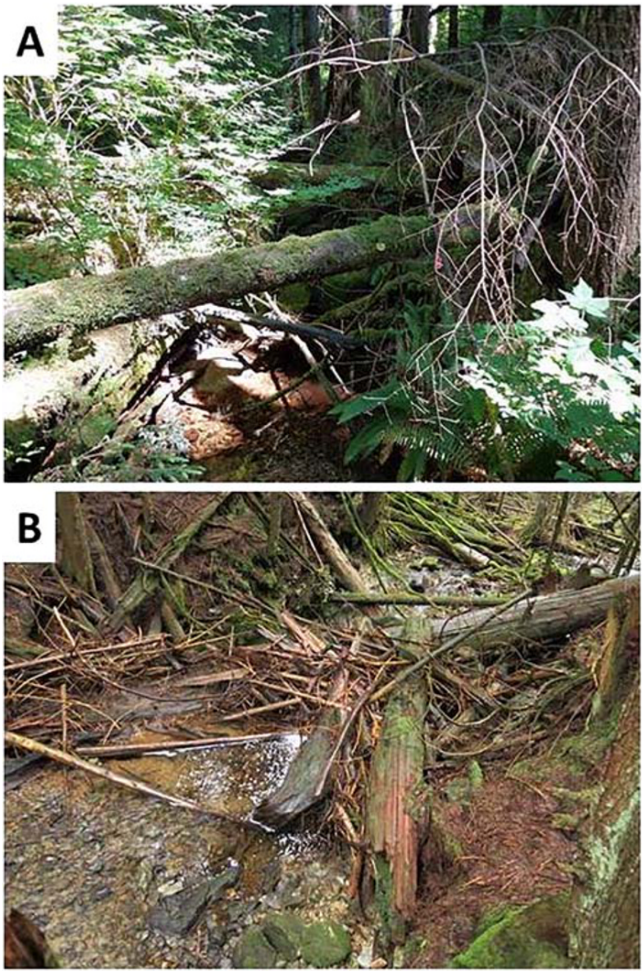

Figure 2. Large wood recruitment in headwater streams of Malcolm Knapp Research Forest. (A) Logs suspended above the channel. (B) Logs inside the channel (non-suspended wood) providing physical structure for the stream ecosystem – see the big large wood trapping smaller wood pieces and forming a dammed pool habitat above the log jam. Source: Felipe Rossetti de Paula. [Colour figure can be viewed at wileyonlinelibrary.com]

small log also initially classified as 1 may have decomposed faster to decay class 3 or more).

Statistical analysis

Wood measures were tested for differences between sampling years and suspended status. To evaluate date, we paired each sampling unit. For the analysis of continuous data, we used Generalized Linear Mixed Effect Models (GLMMs) using each individual LW piece as a sampling unit, sites (streams) and pair as a random effect, and years as the factor. We also tested lengths and diameters between sampling years for the most representative classes of decay change. In this analysis, we tested models with and without site as a random effect, and after comparing models by Akaike's Information Criterion (AIC) adjusted for small sample size (AICc; models with the lowest AICc are considered the most parsimonious in a candidate model set; Burnham and Anderson, 2002), we kept site only if the fit of the model was better than the model without it. For count data (abundance of logs), we used GLMM using stream as the sampling unit and pair as a random effect in the model. We also tested the number of logs for the most representative classes of decay change. To evaluate suspended status in 2015, we included sites (streams) as a random effect in all analysis as each sampled stream had both SUSP and NOSUSP wood. We did the same comparison for 2006 using the same coding (SUSP and NOSUSP) for simplicity although all logs in 2006 were suspended. The objective is to evaluate how the initial log conditions may have affected wood changes (i.e. SUSP woods that later became NOSUSP could have lower initial measures of length and diameter than SUSP woods that remained as SUSP in the second sampling). Therefore, for 2006, SUSP logs are those that were suspended and remained suspended in 2015 while NOSUSP are those that were suspended but changed status to non-suspended in 2015.

For continuous data we used GLMM considering each individual piece of LW as a sampling unit, site as a random effect, and suspended status as a factor. For count data, sites were the sampling unit, suspended status were the factor, and sites the random effect in the GLMM. For all analysis, we applied a log transformation on continuous data (if data had no normal distribution) and specified the appropriate link function (Poisson) for count data.

We also tested wood measures for differences among riparian management treatments. For continuous data, we used GLMM using each individual LW piece as a sampling unit, streams as a random effect, and treatment as a factor. For count data, we used Generalized Linear Models (GLMs), and specified an appropriate link function (Poisson). Continuous data were log transformed if they were not normally distributed. If overdispersion was present in the GLM analysis, we changed the link function to quasi-Poisson link function. When significant differences among groups were found, we applied a *post hoc* test (Tukey) using the glht function of *multcomp* package (Hothorn *et al.,* 2008).

We then fitted multiple regression models for the variables DCHANGE, BREAK, BCHANGE, TCHANGE, and STATUS in order to evaluate the factors that affect wood change. For DCHANGE, we fitted models using ordinal regression due to the ordinal nature of this response variable (Christensen, 2018). For BREAK, BCHANGE, and TCHANGE we used standard regression models, and for STATUS, we used logistic regression due to the binary nature of this response variable (SUSP = 1 and NOSUSP = 0; Zuur *et al.,* 2009). For all regressions we used GLMMs with individual logs as sampling units, streams as a random effect, and a set of continuous and categorical predictors. Continuous predictors were primarily wood information collected in 2006 [total length (LENGTH), span length (SPALEN), base diameter (BDIAM), mid-span diameter (SPANDIAM), height above bankfull (HABANK), decay (DECAY06)], and stream morphology (BCW and VFW) also from 2006. Measures of wood changes (BREAK, DCHANGE, BCHANGE, and TCHANGE) were also considered in addition to wood and channel data collected in 2006. Categorical predictors included each treatment (TREAT) of riparian management and tree group (GROUP, coniferous or deciduous). We analyzed each response variable using model selection and averaging in R software (R Development Core Team, 2016) following the recommendations of Grueber *et al.* (2011). First, for continuous responses, we limited predictors that were included in the initial model by excluding highly correlated continuous predictors ($r \geq 0.7$) and the categorical predictors that were not significant (after testing the predictor in a univariate analysis with the given response variable). For the binary response STATUS, we also selected predictors using a univariate analysis. After limiting the predictors, we created a full candidate set of models using the dredge function of *MuMIn* package (Bartón, 2009), selected the models with high support (ΔAICc ≤ 2; Burnham and Anderson, 2002), and ran the model averaging to select the most important predictors. The analyses were done following the recommendations of Crawley (2007) and Zuur *et al.* (2009) and using the glmer and lme function of *lme4* (Bates and Maechler, 2009) and *nlme* (Pinheiro *et al.,* 2019) packages, respectively. Ordinal regressions were performed using the clmm2 function of *ordinal* package (Christensen, 2018).

RESULTS

Changes in suspended wood after riparian recruitment

In 2006, 316 logs were measured and classified as suspended. After nine years, the number of suspended wood pieces decreased (Table 3) by 46.5% (147 logs) as part of them was touching the stream bed (NOSUSP, 34.2%, 108 logs) and 19.3% (61 logs) were not found during the sampling. From 2006 to 2015, wood abundance of decay classes 1 and 2 decreased while decay classes 3, 4 and 5 increased, with most of the wood pieces being in decay classes 3 and 4 (Table 3; Figure 3). The majority of wood pieces were in decay classes 3 and 4 for both SUSP and NOSUSP wood, while less decayed classes (1 and 2) were the most common for SUSP wood (Table 3; Figure 3). For decay class 5 there was more NOSUSP than SUSP wood. Although the abundances of wood in decay classes 1, 2, 3, and 4 were all higher for SUSP, only decay classes 1 and 3 were statistically higher than NOSUSP (Table 3). The more common changes observed in decay classes were from classes 1 to 3 (n = 36; 14.28%), 2 to 3 (n = 48; 19.04%), 2 to 4 (n = 65; 25.79%), and 3 to 4 (n = 28; 11.11%; see also Supporting Information Figure S1). Changes to lower decay classes were absent in Figure S1 because they are unlikely, except changes from decay classes 2 to 1 and 3 to 1 as explained previously. No statistical difference was observed for any class of decay change between SUSP and NOSUSP wood (Table 3).

The mean wood length decreased after nine years and the annual rate of change in length was twice higher for NOSUSP than for SUSP (Table 4). For both sampling years, SUSP logs had a larger mean length than NOSUSP logs. Lower values for changes in length (up to 5 m) were the most common for SUSP wood while values above 10 m were the most common for NOSUSP wood (Figure 4). The mean base diameter of logs decreased between sampling years (diameter decreases from base to the top, with natural log taper), while the diameters of the tops increased (diameter increases from top to the base; Table 4). Proportional changes in diameter between sampling years were approximately five times higher for top than base diameter, and the annual rates of change were similar for base and top diameter among TOTAL, SUSP, and NOSUSP wood (Table 4). Wood length and diameters were statistically different between SUSP and NOSUSP, but for measures of wood change, only changes in length were different (Table 5).

The frequency distribution for base diameter shows that most logs were of small diameter and mostly in decay classes 3 and 4 for both SUSP and NOSUSP logs (Figure 5). For the larger logs (diameter > 40 cm), the percentages of SUSP logs in low decay classes (1 and 2) and in more advanced decay classes (3 to 5) were twice those of NOSUSP logs. A high frequency of changes in length was observed for small-diameter wood. The frequency of changes in length was the highest for wood in the diameter class 11 to 20 m, and decreased with increasing diameter. The frequency of changes in length for the largest length class (> 11 m) was low for all diameter classes (Figure 6). Also, lower values for changes in length (0 to 5 m) were the most common for logs that advanced one (DC1) or two (DC2) levels of decay (Figure 7).

The annual rate of changes in length for the most representative decay change classes was similar to the value reported for TOTAL logs. These values were also similar among them (except changes from classes 3 to 4; Table 6). For base and top diameter, more variation was observed among the different

Table 3. Differences in the abundance of logs between sampling years and suspended status.

Sampling years			
	Total abundance		
Logs	2006[a]	2015	Significance (α = 0.05)
SUSP	255	147	**<0.01**
Decay 1	76	17	**<0.01**
Decay 2	134	30	**<0.01**
Decay 3	40	90	**<0.01**
Decay 4	0	105	**<0.01**
Decay 5	0	8	0.16
Suspended status			
	Total abundance (2015)		
Wood condition	SUSP	NOSUSP	Significance (α = 0.05)
Decay 1	15	2	**<0.01**
Decay 2	20	10	0.07
Decay 3	56	36	**0.03**
Decay 4	54	53	0.9
Decay 5	2	6	0.17
Decay change 0	23	13	0.1
Decay change 1	53	38	0.1
Decay change 2	63	52	0.2
Decay change 3	5	9	0.2

[a]Excluding logs not found in 2015.
Note: Bold values indicate significant results.

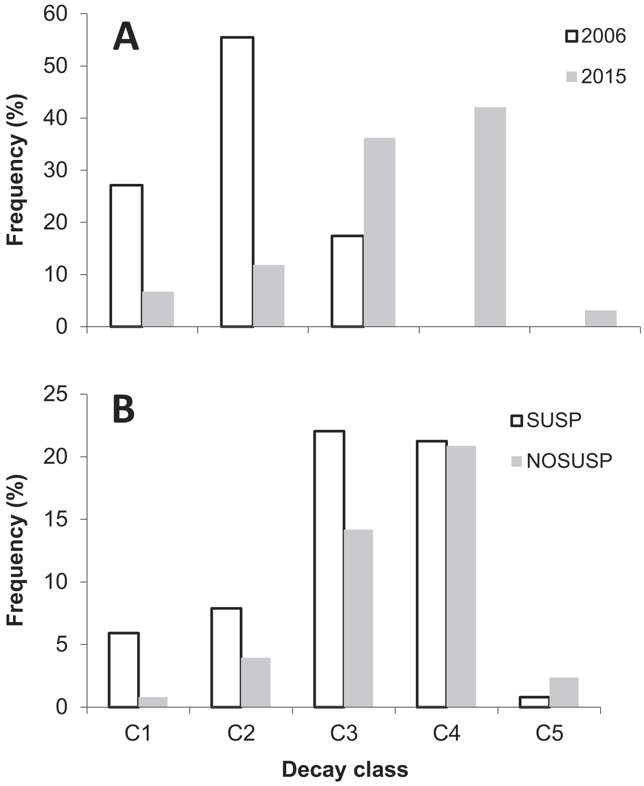

Figure 3. Frequency distribution of wood by decay classes. (A) Decay classes in 2006 (n = 311; five missing values) and 2015 (n = 254; one missing value). (B) Decay classes for SUSP (n = 147) and NOSUSP wood (n = 107) in 2015.

Table 4. Wood measures of length and diameters for 2006 and 2015.

Wood attribute	Logs	Measure 2006	Measure 2015	Absolute change (cm)	Proportional change (%)	Annual rate (cm/yr)	Significance (α = 0.05)
	TOTAL	14.1 (±8.2)	10.8 (±7.5)	3.3	23.4	0.36	<**0.01**[a]
	SUSP	15.3 (±8.3)	12.8 (±7.3)	2.5	16.3	0.27	
Length (m)	NOSUSP	12.4 (±7.9)	8.2 (±6.9)	4.3	34.6	0.47	
	TOTAL	21.3 (±12.7)	19.1 (±11.4)	2.2	10.3	0.24	<**0.01**[a]
	SUSP	22.2 (±13.4)	19.9 (±11.8)	2.2	9.9	0.25	
Base diameter (cm)	NOSUSP	20.2 (±11.7)	18.0 (±10.9)	2.1	10.4	0.24	
	TOTAL	5.9 (±5.59)	9.3 (±6.2)	3.3	55.9	0.37	<**0.01**[a]
	SUSP	5.0 (±4.99)	8.4 (±6.2)	3.3	66	0.36	
Top diameter (cm)	NOSUSP	7.1 (±6.15)	10.6 (±6.1)	3.5	49.3	0.39	

[a]For TOTAL logs.
Note: Means are followed by values of one standard deviation in parentheses. Bold values indicate significant results.

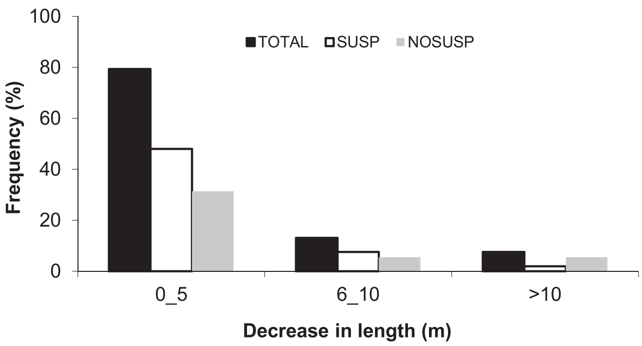

Figure 4. Frequency distribution of changes in wood length for TOTAL (n = 252; three missing values), SUSP (n = 145), and NOSUSP (n = 107).

Table 5. Wood attributes for SUSP and NOSUSP logs.

Wood attributes	2015 SUSP	2015 NOSUSP	Significance (α = 0.05)
Length (m)	12.8(±7.3)	8.2(±6.9)	<**0.01**
Change in length (m)	2.5(±5.2)	4.3(±6.4)	<**0.01**
Base diameter (cm)	20(±11.8)	18(±10.8)	<**0.01**
Change in base diameter (cm)	3.7(±4.4)	3.3(±4.0)	0.51
Top diameter (cm)	8.4(±6.2)	10.6(±6.1)	<**0.01**
Change in top diameter (cm)	4.1(±5.5)	4.9(±5.8)	0.18

Note: Means followed by values of one standard deviation in parentheses. Bold values indicate significant results.

classes and when compared to the values reported for TOTAL logs (Table 6). Wood attributes were statistically different between years for most classes of decay change (Table 6). In 2006, wood pieces were on average suspended 0.98 m [±0.70 standard deviation (SD)] above the stream bed considering TOTAL logs. This value was higher for SUSP [1.14 m (±0.66 SD)] than NOSUSP [0.76 m (±0.68 SD); $p < 0.01$].

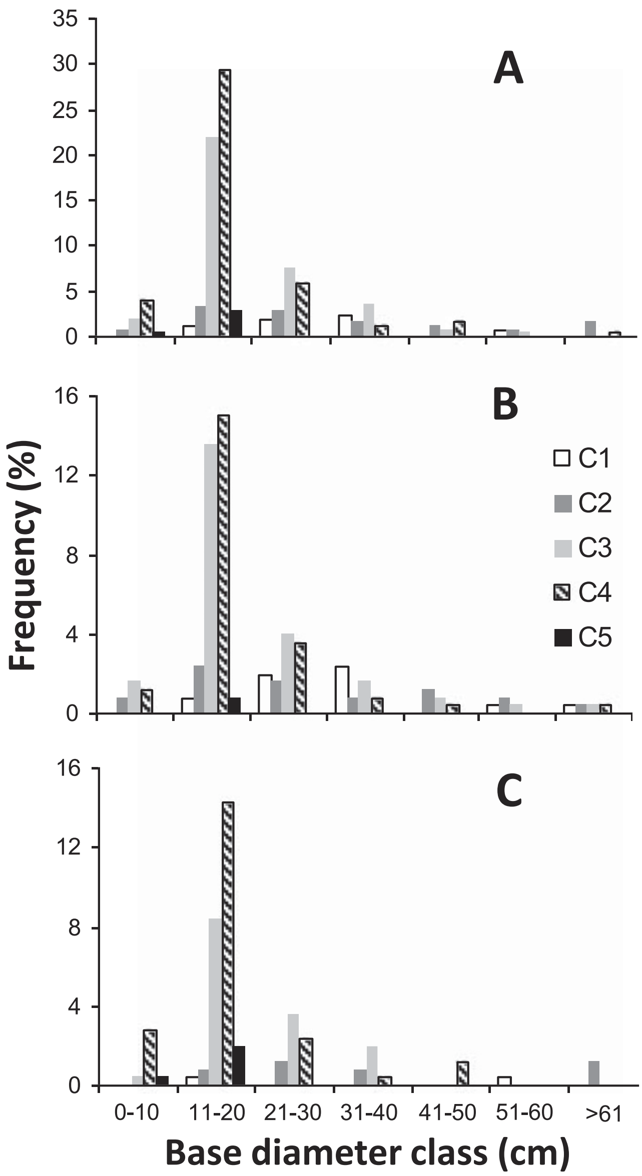

Figure 5. Frequency distribution of base diameter (2015) by decay class. (A) TOTAL (n = 254; one missing value). (B) SUSP (n = 147). (C) NOSUSP (n = 107).

Effects of riparian management practices on LW changes

Treatment B10 had the highest annual rates of changes among all treatments for TOTAL, SUSP, and NOSUSP, and the lowest rates were observed for treatment T50 (except base diameter; Table S2). In general, the annual rates of changes were higher for NOSUSP than SUSP wood for all treatments. We found significant differences between riparian management practices in some variables of LW changes. These variables included initial wood length (TOTAL, SUSP, and NOSUSP logs), base

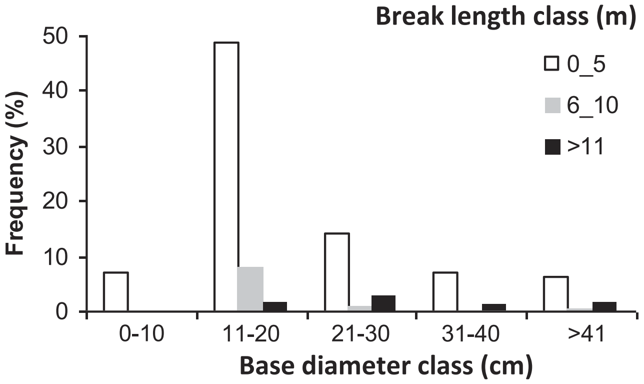

Figure 6. Frequency distribution of base diameter by changes in wood length (represented by the white, gray, and black bars). Sample size = 252 (three missing values).

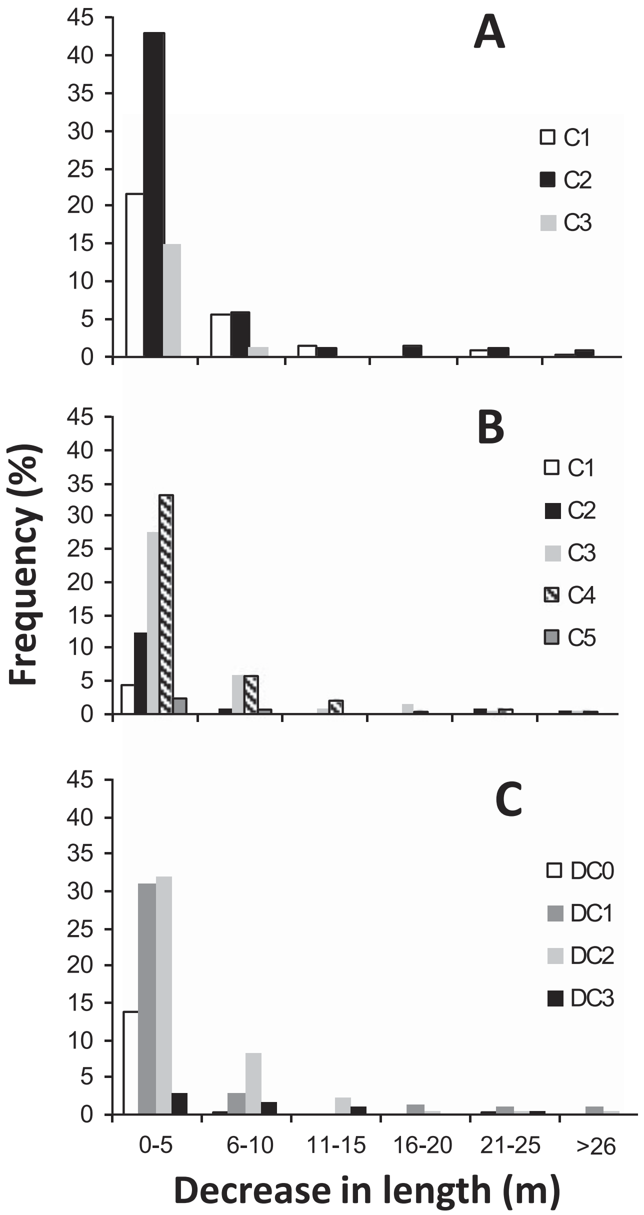

Figure 7. Frequency distribution of changes in wood length by decay (C1–C5) and decay change (DC0–DC3) over a nine-year time frame. (A) Decay 2006 (n = 249; missing values: one length and five decay). (B) Decay 2015 (n = 252; missing values: two length and one decay). (C) Decay change (n = 248; missing values: five decay change and two length).

diameter for SUSP wood in 2015, top diameter for NOSUSP wood in 2015, changes in top diameter (TOTAL and SUSP), and wood abundance for decay classes 1 and 2 in 2015 (Table 7). In 2006, logs were smaller in T50 than the other treatments, and after nine years, logs in REF, B30, and B10 became smaller and similar to logs in T50 (logs in T50 had smaller changes in wood length). Logs in REF had lower values of top and base diameter than in B30 and B10, and wood in treatment B10 experienced greater changes in top diameter than in T50. For decay class 1, treatment B10 had more logs than B30, and for decay class 2, REF had more logs than B10 and T50.

Factors affecting LW changes

During predictor selection, we excluded span length and mid-span diameter from the analysis as they were highly correlated with total length and base diameter, respectively. We found that wood changes after nine years were related to valley and initial LW characteristics. Wood pieces that had higher changes in decay class had smaller base diameter, were less decayed, and were closer to the water (Table 8). Wood pieces with greater changes in base diameter had larger diameter, had higher reductions in length, and were shorter (Table 9). Wood pieces with greater changes in top diameter had higher reductions in length, were longer, had larger base diameter, and were less decayed (Table 10). Wood pieces that had higher reductions in length had greater changes in decay, were more decayed, were longer, and had greater changes in top diameter (Table 11). For wood status, the probability of a log being SUSP was lower with wider valley floor and higher reductions in length, and was higher when logs were longer and more distant from stream water (Table 12). Riparian buffer treatments were not selected in any models for all the response variables tested.

DISCUSSION

Changes in suspended wood after riparian recruitment

Seventeen years post-harvest of the riparian buffers and nine years after initial measurement, we found that suspended LW advanced in decomposition, became shorter, and 34% of them fallen in the stream bed. This is consistent with findings in other studies, where LW experiences reductions in density, structural integrity, and length, as it decomposes over time (Fraver *et al.,* 2013; Merten *et al.,* 2013 ; Iroumé *et al.,* 2017). Changes in LW decomposition state and log lengths were consistent with findings elsewhere, but our annual average rate of change in length (0.36 m/yr) was higher than the rate (0.26 m/yr) found by Merten *et al.* (2013). Our sampled wood pieces were initially longer as we sampled suspended trees that had fallen across the streams while others sampled wood pieces that were mostly inside the channel (Warren and Kraft, 2008; Merten *et al.,* 2013; Iroumé *et al.,* 2017), which had already experienced some degree of decay and breakage post-recruitment.

Over the nine year period, we found lower LW base diameter and larger top diameter. For conifers, diameter generally decreases from base to the top of the logs (e.g. Schreuder *et al.,* 1993) and we found that logs were 3 m shorter on average over the sampling period. In the long term, breakage at each end of a section of LW followed by decay and abrasion leaded to the measurement of different locations in a log than the original location, thus resulting in different diameters. Thus,

Table 6. Changes in wood length and diameters in the most representative classes of decay change.

Wood attribute	Decay change class	Measure 2006	Measure 2015	Absolute change	Proportional change (%)	Annual rate of change	Significance (α = 0.05)
	1-3	13.2 (±4.9)	9.6 (±5.6)	3.5	26.5	0.39	<**0.01**
	2-3	14.3 (±8.0)	10.7 (±7.3)	3.6	24.4	0.39	<**0.01**
	2-4	13.0 (±8.7)	9.3 (±5.8)	3.6	28.4	0.40	<**0.01**
Length (m)	3-4	9.8 (±4.3)	8.5 (±4.4)	1.3	13.3	0.14	<**0.01**
	1-3	14.5 (±4.9)	14.0 (±3.8)	0.9	6.0	0.10	0.2
	2-3	23.9 (±12.5)	21.4 (±11.3)	2.5	10.5	0.27	<**0.01**
	2-4	18.8 (±10.2)	17.0 (±9.4)	1.7	9.0	0.18	<**0.01**
Base diameter (cm)	3-4	18.5 (±6.4)	15.8 (±4.2)	2.7	14.6	0.30	<**0.01**
	1-3	1.9 (±3.1)	6.5 (±3.4)	4.5	236.8	0.50	<**0.01**
	2-3	7.9 (±6.4)	11.7 (±6.5)	3.8	48.7	0.42	<**0.01**
	2-4	6.7 (±5.5)	9.3 (±7.5)	2.6	38.8	0.29	<**0.01**
Top diameter (cm)	3-4	9.2 (±3.9)	9.8 (±3.2)	0.5	5.4	0.06	0.19

Note: Bold values indicate significant results.

these processes acting in the log would result in the smaller base and larger top diameters observed here.

The changes in wood decay and dimensions (especially length) observed in this study apparently contributed to changes in wood status from SUSP to NOSUSP (i.e. the largest values for changes in length were observed for NOSUSP logs). However, a high number of logs (46.5%, n = 147) were still suspending the channel between 2006 and 2015. These suspended logs were thicker (base diameter), longer, suspended higher above stream banks, and were mostly less decayed than NOSUSP logs. It is also important to note that bed-mobilizing flows and landslides in our small streams were probably too small and infrequent to induce hydraulic damage and downstream transport of these remaining suspended wood pieces during the time frame of this study [see Hassan *et al.* (2005); in the field, we observed that most logs decayed in place and moved short distances (personal observations)]. This indicates that recruitment of suspended-wood onto the streambed can be a long-term (multi-annual to decadal) process in small streams. Therefore, the transitional process from suspended to non-suspended LW can be an important mechanism underlying a lagged effect of riparian tree fall on headwater streams with implications for LW residence time and functions in streams.

Effects of riparian management practices on LW changes

Although we expected greater LW changes in the riparian treatments with greater extent of alterations of riparian forest (B10 and T50), we found that treatment T50 had the lowest reductions in length in comparison with the other treatments, possibly from slower decomposition rates. This reduced rate of decomposition could be attributed to greater light and heat after riparian alteration (Brosofske *et al.,* 1997; Kiffney *et al.,* 2003; Moore *et al.,* 2005), which may have increased log drying rates, decreased relative humidity and riparian moisture, especially in summer months where the water level is reduced considerably in the streams of this region. However, we found that the relative abundance of wood pieces in advanced decay were similar for all treatments. Another possible explanation is that T50 had the smallest log length values at the beginning of the study, and small logs were found to have lower changes in wood length (Merten *et al.,* 2013; Iroumé *et al.,* 2017). The results we found for top diameter on NOSUSP wood pieces may suggest greater changes in buffer treatments in comparison with REF; however, the results for TCHANGE does not support this as treatments B30, B10, and T50 were not statistically different from REF. Therefore, our findings revealed limited influences of riparian management on many aspects of wood change, despite its known effects on light incidence and water temperature in the study sites (Kiffney *et al.,* 2003).

In a recent study, Yeung *et al.* (2017) found that sites B10 and T50 of this study had decreased canopy openness after 15 and nine years following riparian forest harvesting and thinning, respectively. Therefore, we speculate that the alterations of forest canopy that had initially increased light, water temperature, and stream metabolism in these streams (Kiffney *et al.,* 2003; Yeung *et al.,* 2017) recovered quickly to pre-disturbance levels (Webster *et al.,* 1992; McTammany *et al.,* 2007) due to crown expansion of surviving overstory trees. Consequently, any short-term differences in rates of wood decomposition among our treatments may have lasted only for a short time period, and have had more impact on movement between initial decay classes. Movement into higher decay classes is a longer term process (Merten *et al.,* 2013; Iroumé *et al.,* 2017). Therefore, forest canopy recovery may have resulted in similar LW changes among riparian management treatments for most of the variables considered in this study.

Factors affecting LW changes

Wood in streams is more likely to experience biological and physical changes when they are smaller in diameter, longer, and less decayed (Merten *et al.,* 2013; Iroumé *et al.,* 2017). We found that small-diameter wood pieces decayed faster than large-diameter wood. Diameter is an important factor for wood decay as it affects the rate of biological decomposition through differences in surface area to volume ratios (Spänhoff and Meyer, 2004; Merten *et al.,* 2013; Iroumé *et al.,* 2017). We also found that more decayed wood had higher reductions in length and smaller change in decay class. Wood in advanced decomposition loses structural integrity over time that facilitates breaks (Merten *et al.,* 2013; Iroumé *et al.,* 2017), but for this decayed material most of the wood structural integrity is already lost, reducing decay rates in comparison with less decayed material (Harmon *et al.,* 2000; Iroumé *et al.,* 2017). Wood length is also important for breaks as longer pieces are subject to greater hydraulic leverage when inside the channel

Table 7. Results of pairwise comparisons among riparian forest treatments.

Variables	Statistical model	Test	Significance (α = 0.05)	Tukey test
Large wood (LW) abundance 2006				
TOTAL	GLM (Quasipoisson)	ChiSquare	0.55	—
Decay 1	GLM (Quasipoisson)	ChiSquare	0.14	—
Decay 2	GLM (Quasipoisson)	ChiSquare	0.98	—
Decay 3	GLM (Quasipoisson)	ChiSquare	0.06	—
LW abundance 2015				
TOTAL	GLM (QuasiPoisson)	ChiSquare	0.6	—
NOSUSP	GLM (QuasiPoisson)	ChiSquare	0.22	—
SUSP	GLM (QuasiPoisson)	ChiSquare	0.43	—
Decay 1	GLM (Poisson)	ChiSquare	<**0.01**	B10>B30
Decay 2	GLM (Poisson)	ChiSquare	<**0.01**	REF>B10,T50
Decay 3	GLM (Quasipoisson)	ChiSquare	0.17	—
Decay 4	GLM (Poisson)	ChiSquare	0.49	—
LW decay change (abundance)				
Decay change 0	GLM (Poisson)	ChiSquare	0.22	—
Decay change 1	GLM (Poisson)	ChiSquare	0.16	—
Decay change 2	GLM (QuasiPoisson)	ChiSquare	0.81	—
Decay change 3	GLM (QuasiPoisson)	ChiSquare	0.11	—
LW length 2006				
TOTAL[a]	GLMM	F	<**0.01**	T50<REF,B30,B10
NOSUSP[a]	GLMM	F	**0.02**	T50<REF,B30,B10
SUSP[a]	GLMM	F	**0.03**	T50<B30,B10
LW length 2015				
TOTAL[a]	GLMM	F	0.34	—
NOSUSP[a]	GLMM	F	0.38	—
SUSP[a]	GLMM	F	0.12	—
LW length reduction				
TOTAL[a]	GLMM	F	0.06	—
NOSUSP[a]	GLMM	F	0.09	—
SUSP[a]	GLMM	F	0.19	—
LW base diameter 2006				
TOTAL[a]	GLMM	F	0.32	—
NOSUSP[a]	GLMM	F	0.49	—
SUSP[a]	GLMM	F	0.08	—
LW base diameter 2015				
TOTALr[a]	GLMM	F	0.27	—
NOSUSP[a]	GLMM	F	0.64	—
SUSP[a]	GLMM	F	**0.04**	REF<B30,B10
LW base diameter change				
TOTAL[a]	GLMM	F	0.53	—
NOSUSP[a]	GLMM	F	0.54	—
SUSP[a]	GLMM	F	0.42	—
LW top diameter 2006				
TOTAL	GLMM	F	0.24	—
NOSUSP	GLMM	F	0.25	—
SUSP	GLMM	F	0.28	—
LW top diameter 2015				
TOTAL[a]	GLMM	F	0.20	—
NOSUSP[a]	GLMM	F	**0.03**	REF<B30,B10
SUSP[a]	GLMM	F	0.80	—
LW top diameter change				
TOTAL	GLMM	F	**0.03**	B10>T50
NOSUSP	GLMM	F	0.13	—
SUSP	GLMM	F	**0.05**	B10>T50
Stream geomorphology				
Bankfull channel width	Anova	F	0.43	—
Valley floor width[a]	Anova	F	0.4	—

[a]Log transformed data.
Note: Bold values indicate significant results.

(Tanaka and Yagisawa, 2009). As wood pieces were suspending the channel at the beginning of this study, longer pieces might be more exposed to leverage forces acting on the suspending section of the wood (gravity force for wood suspended higher from stream water, and gravity plus hydraulic forces for wood sections suspended closer to stream water).

We expected that most of our SUSP wood would have changed their status to NOSUSP due to increased wood changes caused by wetting and drying conditions and also by hydraulic damages over the years. These changes would reduce wood integrity and cause wood collapse. However, 15 years post-harvest, we found that 46.5% of sampled logs were still suspending the channel. We found that wider

Table 8. Results of model selection and averaging for the response variable decay change (DCHANGE)

Response: DCHANGE				
Model selection				
Global model: BDIAM+LENGTH+DECAY06+TREAT+GROUP+VFW+BCW+HABANK				
Models selected	df	AICc	ΔAICc	Weight
BDIAM+DECAY06+HABANK	7	505.25	0	0.23
BDIAM+DECAY06+GROUP+HABANK	8	505.91	0.66	0.16
BDIAM+BCW+DECAY06+HABANK	8	505.91	0.66	0.16
BDIAM+DECAY06+HABANK	8	506.36	1.11	0.13
BDIAM+BCW+DECAY06+GROUP+HABANK	9	506.62	1.37	0.11
BDIAM+DECAY06+GROUP+HABANK+VFW	9	506.85	1.6	0.1
BDIAM+BCW+DECAY06+HABANK+VFW	9	506.96	1.71	0.1
Model averaging				
	Estimate	Standard error	*z* Value	Pr(>|*z*|)
0|1	-7.000	1.003	6.974	<**0.01**
1|2	-4.563	0.942	4.842	<**0.01**
2|3	-1.043	0.924	1.128	0.259
BDIAM	-0.062	0.012	5.019	<**0.01**
DECAY06	-1.123	0.248	4.524	<**0.01**
HABANK	-0.009	0.002	4.104	<**0.01**
GROUPDECI	0.196	0.360	0.544	0.586
BCW	-0.097	0.178	0.544	0.586
VFW	-0.016	0.035	0.464	0.643

Table 9. Results of model selection and averaging for the response variable changes in base diameter (BCHANGE)

Response: BCHANGE				
Model selection				
Global model: DECAY15+DCAHNGE+BDIAM+LENGTH+TREAT+VFW+HABANK+BREAK				
Models selected	df	AICc	ΔAICc	Weight
BDIAM+BREAK+LENGTH	6	102.55	0	0.53
BDIAM	4	102.82	0.27	0.47
Model averaging				
	Estimate	Standard error	*z* Value	Pr(>|*z*|)
BDIAM	0.413	0.071	5.768	<**0.01**
BREAK	0.134	0.042	3.175	<**0.01**
LENGTH	-0.183	0.05	3.064	<**0.01**

Table 10. Results of model selection and averaging for the response variable changes in top diameter (TCHANGE)

Response: TCHANGE				
Model selection				
Global model: DECAY06+DECAY15+BDIAM+LENGTH+TREAT+HABANK+BREAK				
Models selected	df	AICc	ΔAICc	Weight
BREAK+DECAY06+LENGTH	6	100.19	0	0.68
BDIAM+BREAK+DECAY06	6	101.67	1.48	0.32
Model averaging				
	Estimate	Standard error	*z* Value	Pr(>|*z*|)
BREAK	0.289	0.044	6.462	<**0.01**
DECAY06	-0.156	0.039	3.953	<**0.01**
LENGTH	0.147	0.041	3.505	<**0.01**
BDIAM	0.121	0.036	3.324	<**0.01**

valley floors decreased the probability of wood to remain suspended. In alluvial valleys, stream channels are wider (less incised), increasing the chances of at least part of trees falling inside the channel (Naiman *et al.*, 2010), or when trees suspend the channel, they will be closer to the water. In contrast, if channels are narrow and incised (usually with

Table 11. Results of model selection and averaging for the response variable changes in wood length (BREAK)

Response: BREAK				
Model selection				
Global model: TREAT+GROUP+DECAY06+DCHANGE+LENGTH+HABANK+BCHANGE+TCHANGE				
Models selected	df	AICc	ΔAICc	Weight
DCHANGE+DECAY06+HABANK+LENGTH+TCHANGE	8	1438.84	0	0.43
DCHANGE+DECAY06+HABANK+LENGTH+BCHANGE+TCHANGE	9	1438.97	0.13	0.41
DCHANGE+DECAY06+HABANK+LENGTH+TCHANGE	7	1440.8	1.96	0.16
Model averaging				
	Estimate	Standard error	*z* Value	Pr(>|z|)
DCHANGE	3.541	0.650	5.410	<**0.01**
DECAY06	2.437	0.680	3.565	<**0.01**
HABANK	0.947	0.715	1.320	0.186
LENGTH	4.670	0.718	6.467	<**0.01**
TCHANGE	4.292	0.661	6.457	<**0.01**
BCHANGE	0.267	0.502	0.530	0.595

Table 12. Results of model selection and averaging for the response variable suspended status (STATUS)

Response: STATUS				
Model selection				
Global model: VFW+DCHANGE+BDIAM+LENGTH+HABANK+BREAK				
Models selected	df	AICc	ΔAICc	Weight
BREAK+HABANK+LENGTH+VFW	6	273.5	0	0.49
BDIAM+BREAK+HABANK+LENGTH+VFW	7	274.5	1.05	0.29
BREAK+DCHANGE+HABANK+LENGTH+VFW	7	275.1	1.67	0.21
Model averaging				
	Estimate	Standard error	*z* Value	Pr(>|z|)
(Intercept)	0.510	0.332	1.531	0.126
BREAK	-2.120	0.435	4.852	<**0.01**
HABANK	1.068	0.415	2.561	<**0.01**
LENGTH	1.948	0.565	3.434	<**0.01**
VFW	-1.507	0.639	2.345	**0.019**
BDIAM	-0.159	0.378	0.420	0.674
DCHANGE	-0.057	0.215	0.265	0.791

higher banks), falling trees will more likely be suspended high above the channel and distant from stream water (Bahuguna *et al.,* 2010), thus reducing wood changes and maintaining the wood's structural integrity necessary to sustain the wood suspending the channel.

Logs suspended high above the water level likely dry more quickly due to higher exposure to light, heat, lower humidity and reduced wetting by stream water, which limits decomposition rates in seasonally dry terrestrial environments (Naiman *et al.,* 2005; Chapin *et al.,* 2011), such as MKRF. Moreover, logs suspended higher above the channel would not be exposed to hydraulic damage during high flows (Merten *et al.,* 2010), while wood pieces in contact with the flow may lose branches and bark (due to abrasion by sediments and physical structures in the channel), or even be broken or dragged (Moulin and Piegay, 2004; Tanaka and Yagisawa, 2009). Merten *et al.* (2013) found that suspended wood had greater changes in wood attributes. However, we suspect that their wood suspended above the channel might not be as high above the stream as the ones in this study as most of their sampled streams were wider (BCW varying from 5.3 to 24.4 m; Merten *et al.,* 2011) than our streams. Thus, their suspended wood was likely closer to the water. In another study, Merten *et al.* (2010) found that wood pieces located higher above stream water were less affected by stream flow and had lower changes, a result similar to our findings.

It seems that the height of wood from stream water may influence how fast wood changes by a combination of biochemical and mechanical processes acting on the wood piece. In this study, all wood pieces measured were initially suspending the channel as streams were mostly incised and logs were longer than the active channel width (Bahuguna *et al.,* 2010). However, some suspended trees were closer to the water level, which may have accelerated wood changes (Bilby *et al.,* 1999**;** Merten *et al.,* 2010) and wood fall inside streams. In this context, channel morphology may exert a strong influence on wood changes. Our results showed a tendency of slow decay change for wood pieces located higher above the stream, and thus, they had a greater chance of remaining as suspending the channel.

Wood decay may be a first step to change wood status from SUSP to NOSUSP by facilitating wood breakage. However, we found no effects of wood decay on wood status in this study. It is possible that decay change did not affect suspended status if wood integrity exhibited a non-linear, threshold response where a greater extent of decay change from classes 1 to 3 was not strong enough to cause a change in suspended status. However, a change in suspended status might be triggered by an advance in decay class from 4 to 5 that leads to wood collapse (Jones *et al.,* 2011). Also, other processes not addressed here (i.e. slope failure and channel realignment) are also important for suspended wood entering the channel, while other wood aspects may delay the recruitment of suspended wood to inside the channel. For example, attached roots in those remaining suspended woods may have increased wood anchoring (Iroumé *et al.,* 2018). In addition, wood species decay at different rates and the vast majority of our sampling logs were conifers, which loses wood density and structural integrity at slower rates compared to the dominant deciduous trees found in our study area (Fraver *et al.,* 2013).

Limitations

We recognize that our measure of decay (based on visual criteria) is not as robust an indicator of wood structural integrity as wood density (Merten *et al.,* 2013; Iroumé *et al.,* 2017). This visual classification also provided some minor errors between the sampling periods due to differences in sampler's ability to classify logs in a given decay class. Therefore, wood density could have provided a better measure of decay condition and change in suspended status in this study. We recommend quantifying wood density to more accurately reflect wood decay in future long-term studies.

An important limitation is related to the location where the tag was placed in the log. The tag was initially placed in the suspending section of the log without distinguishing the different log sections (base, middle, top). However, the tag position can strongly influence the results. If the tag is placed in the top section, and after the log breaks, only this section is re-measured (here we just re-measured the pieces with the tag and excluded the broken pieces in 2015 even if they were still in place), the future measurements of wood changes will be higher. This can overestimate the rates of wood changes since the other parts of the log (base/middle) may still remain in place but change slowly. This situation can generate the largest errors in the long term.

In contrast, if the tag was placed in the base (or in the middle) of the log and this is the section that remains in place, future measures will show lower rates of changes. This situation will underestimate the rates of change in the short term since changes in the top sections are faster and more frequent. However, this situation generates lower errors in the long term since the base and mid sections of the log remain in the channel for longer. Therefore, our approach may have added bias in the analysis if any of the situations mentioned earlier prevailed in our sampling. In this study, our objective was to assess general patterns of wood changes in the long term starting from one sampling scheme that was not initially designed for this objective (Bahuguna *et al.,* 2012). Therefore, it is hard to know if any of these conditions is strongly affecting our results. Moreover, this approach did not allow us to obtain more precise values for annual rates of wood changes. However, our work still provided relevant information about the long-term dynamic of suspended wood in confined channels.

It is very likely that for entire log pieces, the rates of changes are fast in the first years due to breaks and decay in the thinnest sections closest to the top, and then slowdown in the following years since the remaining material breaks and decomposes slowly (Fraver *et al.,* 2013). Therefore, it is important to consider where the tag is placed in studies that aim to quantify more precisely long-term wood changes. For future studies, we recommend a more intensive sampling in the long term (considering a short time interval between samplings, i.e. annual) to track breaks and other changes in each section of the log and at each moment that the log breaks, including the log parts disconnected from the main piece. Tracking the fine scale changes in the short term for a long time period would allow a very precise quantification of log changes and would advance our understanding about the dynamics of wood in streams, especially for suspended wood in confined channels where their residency time is longer.

This intensive and precise sampling would also avoid the uncertainty of measurements when determining wood changes in long-term studies, especially regarding changes in diameter as already pointed by Iroumé *et al.* (2017). These errors might be associated with the precision in defining where the first measure was taken at the base and top sections of the logs, especially because breaks followed by decay and abrasion lead to the measurement of different locations in a log than the original location, thus resulting in different diameters. We believe that these limitations had limited influences on the patterns we described here since our objective was to characterize general patterns of wood changes and not quantify precisely the rates of wood changes along time.

Final remarks

This work is part of a long-term study that advances our understanding about the temporal dynamics of suspended wood in confined valleys. In the years shortly after the initial buffer exposure by harvesting, there is a pulse of wood recruitment by windthrow, but this LW takes decades to recruit into the stream channel (Bahuguna *et al.,* 2010, 2012). During this time suspended wood is a substrate for other organisms (Kumar *et al.,* 2018; Chang *et al.,* 2019) and provides partial shade for the stream (Figure 2a), but it has limited influences on stream bed processes. When LW is recruited, it is often in an advanced state of decay, and in shorter pieces that may have shorter in-stream residency time than logs entrained while undecayed (wood rots slowly when always saturated).

Our LW survey in confined valleys within a temperate, coastal rainforest indicates the timescale and major intrinsic/extrinsic drivers of changes in LW decay and positions. Consistent with the conceptual framework of LW dynamics by Jones *et al.* (2011), most fallen trees or snags that enter the channel at early decay levels are in the suspended (bridge) position with limited influences on stream bed processes and functions. Our results show that suspended wood may remain stable and persist in such position for decades, until wood decomposition results in its transitions to 'partial bridge' or 'loose' positions. The channel-suspended stage can therefore enhance LW residence time due to reduced biological and physical decay and downstream transport, and importantly contribute to the long residence time of LW in confined valleys. The suspended stage can also exert a strong control on LW in-stream functions by mediating wood inputs to the stream bed over time. We found that channel morphology and the height of suspended wood from the water can strongly influence the duration of the channel-suspended stage in our streams.

Given the persistence of suspended wood in confined headwater streams, more long-term studies about suspended LW would improve our understanding of the rates and underlying mechanisms of change in LW decay, position, and hence LW influences on stream functions through time. We recommend fine-scale studies to better understand the influences of abiotic conditions (fluvial versus non-fluvial) on changes in the suspended status of LW, for example, by relating long-term microclimate (e.g. temperature, light, moisture) conditions at the level of suspended wood. Also, how high-flow events change attributes of suspended wood. It is also important to recognize that channel suspended LW plays other roles before it enters the stream, including mediating patch- to reach-scale processes in streams, such as light-related ecological processes (e.g. primary productivity) that influence aquatic food webs and communities. Also, it acts as a substrate for plants and other organisms (Kumar *et al.,* 2018; Chang *et al.,* 2019), which may provide litter for the stream. Therefore, future studies that address the functions at the suspended stage would improve our understanding about the ecological roles of suspended wood in streams.

Conclusion

Wood attributes (length, diameter, decay condition, and height above bankfull) and channel morphology (VFW) were the main drivers of wood change that led to change in status after nine years from first sampling. However, one considerable amount of logs were still suspending the channel. These logs were longer, thicker, and suspended higher above stream bankfull. Riparian management revealed limited influences on many aspects of wood changes. The transition from suspended to non-suspended LW can be a long-term process that can increase wood residence time and reduce LW in-stream functions particularly in confined stream valleys.

Acknowledgements—This project was funded by the Natural Sciences and Engineering Research Council of Canada and by the University of British Columbia. The first author was funded by the Brazilian National Council for Scientific and Technological Development (PhD fellowship, Process 201785/2012-9). The authors would like to thank the staff at the Malcolm Knapp Research Forest, especially Ionut Aron, for their assistance with the project. The authors also thank Tonya Ramey, Elizabeth Perkin, Matthew Wilson, and Marielle Fink for their assistance in the field.

Data Availability Statement

Research data are not shared.

Funding

This project was funded by the Natural Sciences and Engineering Research Council of Canada and by the University of British Columbia. The first author was funded by the Brazilian National Council for Scientific and Technological Development (PhD fellowship, Process 201785/2012-9).

Conflict of interest

The authors declare that they have no conflict of interest.

Author contributions

FRP conceived the study, performed the research, analyzed data, and wrote the article. JSR conceived the study and wrote the article. ACYY performed the research and wrote the article. SJM conceived the study and wrote the article. DB performed the research and wrote the article.

References

Bahuguna D, Mitchell SJ, Miquelajauregui Y. 2010. Windthrow and recruitment of large woody debris in riparian stands. *Forest Ecology and Management* **259**: 2048–2055.

Bahuguna D, Mitchell SJ, Nishio GR. 2012. Post-harvest windthrow and recruitment of large woody debris in riparian buffers on Vancouver Island. *European Journal of Forest Research* **131**: 249–260.

Bartels R, Dell JD, Knight RL, Schaefer G. 1985. Dead and down woody material. In *Management of Wildlife and Fish Habitats in Forests in Western Oregon and Washington*, Brown ER (ed). USDA Forest Service Publication: Portland, OR; 171–186 (USDA For. Serv. Pub. No. R6-FoWL-192).

Bartón K. 2009. MuMIn: multi-model inference. R package, version 0.12.2. Available at: http://r-forge.r-project.org/projects/mumin/.

Bates D, Maechler M. 2009. lme4: Linear mixed-effects models using S4 classes. R package, version 0.999375-31. Available at: http://CRAN.R-project.org/package=lme4.

Bechtold HA, Rosi EJ, Warren DR, Keeton WS. 2017. Forest age influences in-stream ecosystem processes in Northeastern US. *Ecosystems* **20**: 1058–1071.

Benda LE, Sias JC. 2003. A quantitative framework for evaluating the mass balance of in-stream organic debris. *Forest Ecology and Management* **172**: 1–16.

Benke AC, Wallace JB. 2003. Influence of wood on invertebrate communities in streams and rivers. In *The ecology and management of wood in world rivers, Symposium 37*, Gregory SV, Boyer KL, Gurnell AM (eds). American Fisheries Society: Bethesda, MD.

Bilby RE, Bisson PA. 1998. Function and distribution of large woody debris. In *River ecology and management: lessons from the Pacific Coastal Ecoregion*, Naiman RJ, Bilby RE (eds). Springer: New York.

Bilby RE, Heffner JT, Fransen BR, Ward JW, Bisson PA. 1999. Effects of immersion in water on deterioration of wood from five species of trees used for habitat enhancement projects. *North American Journal of Fisheries Management* **19**: 687–695.

Blinn CR, Kilgore MA. 2001. Riparian management practices: a summary of state guidelines. *Journal of Forestry* **99**: 11–17.

Boss SM, Richardson JS. 2002. Effects of food and cover on the growth, survival, and movement of cutthroat trout (*Oncorhynchus clarki*) in coastal streams. *Canadian Journal of Fisheries and Aquatic Sciences* **59**: 1044–1053.

Braithwaite NT, Mallik AU. 2012. Edge effects of wildfire and riparian buffers along boreal forest streams. *Journal of Applied Ecology* **49**: 192–201.

Brosofske KD, Chen J, Naiman RJ, Franklin JF. 1997. Harvesting effects on microclimate gradients from small streams to uplands in Western Washington. *Ecological Applications* **7**: 1188–1200.

Burnham KP, Anderson DR. 2002. *Model selection and multimodel inference: a practical information-theoretic approach*. Springer: New York.

Cadol D, Wohl E. 2010. Wood retention and transport in tropical, headwater streams, La Selva Biological station, Costa Rica. *Geomorphology* **123**: 61–73.

Chang C, Wu F, Wang Z, Tan B, Cao R, Yang W, Cornelissen HC. 2019. Effects of epixylic vegetation removal on the dynamics of the microbial community composition in decaying logs in an Alpine forest. *Ecosystems* **22**(7): 1478–1496. https://doi.org/10.1007/s10021-019-00351-3.

Chapin FS, III, Matson PA, Vitousek PM. 2011. *Principles of terrestrial ecosystem ecology*. Springer: New York.

Chen X, Wei X, Scherer R. 2005. Influence of wildfire and harvest on biomass, carbon pool, and decomposition of large woody debris in forested streams of southern interior British Columbia. *Forest Ecology and Management* **208**: 101–114.

Christensen RHB. 2018. A tutorial on fitting cumulative link mixed models with clmm2 from the ordinal package. Available at: https://cran.r-project.org/web/packages/ordinal/vignettes/clmm2_tutorial.pdf Accessed in September 2018

Crawley JC. 2007. *The R book*. John Wiley & Sons: Chichester.

Cristan R, Aust WM, Bolding MC, Barrett SM, Munsell JF, Schilling E. 2016. Effectiveness of forestry best management practices in the

United States: literature review. *Forest Ecology and Management* **360**: 133–151.

R Development Core Team. 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna

Diez J, Elosegi A, Chauvet E, Pozo J. 2002. Breakdown of wood in the Agüera stream. *Freshwater Biology* **47**: 2205–2215.

Eggert SL, Wallace JB. 2007. Wood biofilm as a food resource for stream detritivores. *Limnology and Oceanography* **52**: 1239–1245.

Elosegi A, Díez JR, Flores L, Molinero J. 2017. Pools, channel form, and sediment storage in wood-restored streams: potential effects on downstream reservoirs. *Geomorphology* **279**: 165–175.

Ferreira V, Chauvet E. 2011. Synergistic effects of water temperature and dissolved nutrients on litter decomposition and associated fungi. *Global Change Biology* **17**: 551–564.

Flores L, Larrañaga A, Díez J, Elosegi A. 2011. Experimental wood addition in streams: effects on organic matter storage and breakdown. *Freshwater Biology* **56**: 2156–2167.

Fraver S, Milo AM, Bradford JB, D'Amato AW, Kenefic L, Palik BJ, Woodall CW, Brissette J. 2013. Woody debris volume depletion through decay: implications for biomass and carbon accounting. *Ecosystems* **16**: 1262–1272.

Grueber CE, Nakagawa S, Laws RJ, Jamieson IG. 2011. Multimodel inference in ecology and evolution: challenges and solution. *Journal of Evolutionary Biology* **24**: 699–711.

Gulis V, Suberkropp KF. 2007. Fungi: biomass, production, and sporulation of aquatic hyphomycetes. In *Methods in Stream Ecology*, Hauer R, Lamberti GA (eds). Academic Press: San Diego, CA.

Harmon ME, Krankina ON, Sexton J. 2000. Decomposition vectors: a new approach to estimating woody detritus decomposition dynamics. *Canadian Journal of Forest Research* **30**: 76–84.

Hassan MA, Hogan DL, Bird SA, May CL, Gomi T, Campbell D. 2005. Spatial and temporal dynamics of wood in headwater streams of the Pacific Northwest. *Journal of the American Water Resources Association* **41**: 899–919.

Hax CL, Golladay SW. 1993. Macroinvertebrate colonization and biofilm development on leaves and wood in a boreal river. *Freshwater Biology* **29**: 79–87.

Hothorn T, Bretz F, Westfall P. 2008. Simultaneous inference in general parametric models. *Biometrical Journal* **50**: 346–363.

Iroumé A, Ruiz-Villanueva V, Picco L. 2017. Breakdown of instream wood in low order forested streams of the southern Chilean mountain ranges. *Forest Ecology and Management* **401**: 17–32.

Iroumé A, Ruiz-Villanueva V, Mao L, Barrientos G, Stoffel M, Vergara G. 2018. Geomorphic and stream flow influences on large wood dynamics and displacement lengths in high gradient mountain streams (Chile). *Hydrological Processes* **32**: 2636–2653.

Jones TA, Daniels LD, Powell SR. 2011. Abundance and function of large woody debris in small, headwater streams in the Rocky Mountain foothills of Alberta, Canada. *River Research and Applications* **27**: 297–311.

Kiffney PM, Richardson JS, Bull JP. 2003. Responses of periphyton and insects to experimental manipulation of riparian buffer width along forest streams. *Journal of Applied Ecology* **40**: 1060–1076.

Kreutzweiser DP, Sibley PK, Richardson JS, Gordon AM. 2012. Introduction and a theoretical basil for using disturbance by forest management activities to sustain aquatic ecosystems. *Freshwater Science* **31**: 224–231.

Kumar P, Chen HYH, Thomas SC, Shahi C. 2018. Epixylic vegetation abundance, diversity, and composition vary with coarse woody debris decay class and substrate species in boreal forest. *Canadian Journal of Forest Research* **48**: 399–411.

Lassetre NS, Piégay H, Dufour S, Rollet A. 2008. Decadal changes in distribution and frequency of wood in a free meandering river, the Ain River, France. *Earth Surface Processes and Landforms* **33**: 1098–1112.

Lecerf A, Richardson JS. 2010. Litter decomposition can detect effects of high and moderate levels of forest disturbance on stream condition. *Forest Ecology and Management* **259**: 2433–2443.

Lee P, Smyth C, Boutin S. 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. *Journal of Environmental Management* **70**: 165–180.

Lujan NK, German DP, Winemiller KO. 2011. Do wood-grazing fishes partition their niche?: morphological and isotopic evidence for trophic segregation in Neotropical Loricariidae. *Functional Ecology* **25**: 1327–1338.

Martins RT, Rezende RS, Gonçalves JF, Jr, Lopes A, Piedade MTF, Cavalcante HL, Hamada N. 2017. Effects of increasing temperature and CO2 on quality of litter, shredders, and microorganisms in Amazonian aquatic systems. *PLoS ONE* **12**(11): 1–15, e0188791.

McDade MH, Swanson FJ, McKee WA, Franklin JF, Sickle JV. 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. *Canadian Journal of Forest Research* **20**: 326–330.

McTammany ME, Benfield EF, Webster JR. 2007. Recovery of stream ecosystem metabolism from historical agriculture. *Journal of the North American Benthological Society* **26**: 532–545.

Merten E, Finlay J, Johnson L, Newman R, Stefan H, Vondracek B. 2010. Factors influencing wood mobilization in streams. *Water Resources Research* **46**: 1–13.

Merten EC, Finlay JC, Johnson L, Newman R, Stefan HG, Vondracek B. 2011. Environmental controls of wood entrapment in upper Midwestern streams. *Hydrological Processes* **25**: 593–602.

Merten EC, Vaz PG, Decker-Fritz JA, Finlay JC, Stefan HG. 2013. Relative importance of breakage and decay as processes depleting large wood from streams. *Geomorphology* **190**: 40–47.

Miquelajauregui Y. 2008. Vegetation community development in small stream buffers eight years after harvesting at Malcolm Knapp Research Forest. MSc Thesis. The University of British Columbia, Vancouver, BC.

Moore RD, Spittlehouse DL, Story A. 2005. Riparian microclimate and stream temperature response to forest harvesting: a review. *Journal of the American Water Resources Association* **41**: 813–834.

Moulin B, Piegay H. 2004. Characteristics and temporal variability of large woody debris trapped in a reservoir on the river Rhone (Rhone): implications for river basin management. *River Research and Applications* **20**: 79–97.

Naiman RJ, Décamps H, McClain ME. 2005. *Riparia: ecology, conservation and management of streamside communities*. Elsevier Academic Press: San Diego, CA.

Naiman RJ, Bechtold JS, Beechie TJ, Latterell JJ, Van Pelt R. 2010. A process-based view of floodplain forest patterns in coastal river valleys of the Pacific Northwest. *Ecosystems* **13**: 1–31.

Parker C, Henshaw AJ, Harvey GL, Sayer CD. 2017. Reintroduced large wood modifies fine sediment transport and storage in a lowland river channel. *Earth Surface Processes and Landforms* **42**: 1693–1703.

Paula FR, Ferraz SFB, Gerhard P, Vettorazzi CA, Ferreira A. 2011. Large woody debris input and its influence on channel structure in agricultural lands of southeast Brazil. *Environmental Management* **48**: 750–763.

Pinheiro J, Bates D, DebRoy S, Sarkar D. 2019. *nlme: Linear and Nonlinear Mixed Effects Models*. R package version 3.1-142. Available at: https://CRAN.R-project.org/package=nlme.

Richardson JS, Feller MC, Kiffney PM, Moore RD, Mitchell SJ, Hinch SG. 2010. Riparian management of small streams: an experimental trial at the Malcolm Knapp Research Forest. *Streamline: Watershed Management Bulletin* **13**: 1–16.

Richardson JS, Naiman RJ, Bisson PA. 2012. How did fixed-width buffers become standard practice for protecting freshwaters and their riparian areas from forest harvest practices? *Freshwater Science* **31**: 232–238.

Richmond AD, Fausch KD. 1995. Characteristics and function of large woody debris in subalpine Rocky Mountain streams in northern Colorado. *Canadian Journal of Fisheries and Aquatic Sciences* **52**: 1789–1802.

Ring E, Johansson J, Sandstrom C, Bjarnadótir B, Finér L, Libiete Z, Lode E, Stupak I, Sætersdal M. 2017. Mapping policies for surface water protection zones on forest land in the Nordic-Baltic region: large differences in prescriptiveness and zone width. *Ambio* **46**(8): 878–893. https://doi.org/10.1007/s13280-017-0924-8.

Rosenfeld JS, Huato L. 2003. Relationship between large woody debris characteristics and pool formation in small coastal British Columbia streams. *North American Journal of Fisheries Management* **23**: 928–938.

Ruiz-Villanueva V, Piégay H, Gaertner V, Perret F, Stoffel M. 2016a. Wood density and moisture sorption and its influence on large wood mobility in rivers. *Catena* **140**: 182–194.

Ruiz-Villanueva V, Piégay H, Gurnell AM, Marston RA, Stoffel M. 2016b. Recent advances quantifying the large wood dynamics in river basins: new methods and remaining challenges. *Reviews of Geophysics* **54**: 611–652.

Schreuder HT, Gregoire TG, Wood GB. 1993. *Sampling methods for multiresource forest inventory*. Wiley: New York.

Sibley PK, Kreutzweiser DP, Naylor BJ, Richardson JS, Gordon AM. 2012. Emulation of natural disturbance (END) for riparian forest management: synthesis and recommendations. *Freshwater Science* **31**: 258–264.

Spänhoff B, Meyer EI. 2004. Breakdown rates of wood in streams. *Journal of the North American Benthological Society* **23**: 189–197.

Steinman AD, Mulholland PJ. 2007. Phosphorous limitation, uptake, and turnover in benthic stream algae. In *Methods in Stream Ecology*, Hauer R, Lamberti GA (eds). Academic Press: San Diego, CA.

Tanaka N, Yagisawa J. 2009. Effects of tree characteristics and substrate condition on critical breaking moment of trees to heavy flooding. *Landscape and Ecological Engineering* **5**: 59–70.

Valente-Neto F, Koroiva R, Fonseca-Gessner AA, Roque FO. 2015. The effect of riparian deforestation on macroinvertebrates associated with submerged woody debris. *Aquatic Sciences* **49**: 115–125.

Warren DR, Kraft CE. 2008. Dynamics of large wood in an eastern U.S. mountain stream. *Forest Ecology and Management* **256**: 808–814.

Warren DR, Bernhardt ES, Hall RO, Jr, Likens GE. 2007. Forest age, wood, and nutrient dynamics in headwater streams of the Hubbard Brook Experimental Forest, NH. *Earth Surface Processes and Landforms* **32**: 1154–1163.

Warren DR, Keeton WS, Kiffney PM, Kaylor MJ, Bechtold HA, Magee J. 2016. Changing forests – changing streams: riparian forest stand development and ecosystem function in temperate headwaters. *Ecosphere* **7**: 1–19. https://doi.org/10.1002/ecs2.1435.

Webster JR, Golladay SW, Benfield EF, Meyer JL, Swank WT, Wallace JB. 1992. Catchment disturbance and stream response: an overview of stream research at Coweeta Hydrologic Laboratory. In *River conservation and management*, Boon PJ, Calow P, Petts GE (eds). John Wiley & Sons: Chichester.

Wohl E, Cenderelli DA, Dwire KA, Ryan-Burkett SE, Young MK, Fausch KD. 2010. Large in-stream wood studies: a call for common metrics. *Earth Surface Processes and Landforms* **35**: 618–625.

Wohl E, Dwire K, Sutfin N, Polvi L, Bazan R. 2012. Mechanisms of carbon storage in mountainous headwater rivers. *Nature Communications* **3**: 1–8. https://doi.org/10.1038/ncomms2274.

Yeung ACY, Lecerf A, Richardson JS. 2017. Assessing the long-term ecological effects of riparian management practices on headwater streams in a coastal temperate rainforest. *Forest Ecology and Management* **384**: 100–109.

Zuur AF, Ieno EN, Walker NJ, Saveliev AA, Smith GM. 2009. *Mixed effect models and extensions in Ecology with R*. Springer: New York.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Wood classification in decay classes (from Bartels *et al*., 1985).
Figure S1. Frequency distribution of changes in wood decay class over a nine-year time frame for TOTAL (n = 250; five missing values), SUSP (n = 146), and NOSUSP (n = 104).
Table S2. Changes in wood length and diameters in each treatment of the study.