Minutes

Meeting	**Regular Council**
Date	**2 July 2019**
Time	**7:00 PM**
Place	**Municipal Hall - Council Chambers**

Present
Mayor Martin Davis
Councillor Bill Elder
Councillor Sarah Fowler
Councillor Lynda Llewellyn

Regrets
Councillor Josh Lambert

Staff
Mark Tatchell, Chief Administrative Officer
Janet StDenis, Finance & Corporate Services Manager

Public
9 members of the public

A. Call to Order

Mayor Davis called the meeting to order at 7:01 p.m.
Mayor Davis acknowledged and respected that Council is meeting upon Mowachaht/ Muchalaht territory

B. Introduction of Late Items and Agenda Changes

Delegation "D1" to be removed.

C. Approval of the Agenda

Fowler/Elder: VOT 342/2019
THAT the Agenda for the July 2, 2019 Regular Council meeting be adopted as amended. **CARRIED**

D. Petitions and Delegations

1 **Josie Miladinovic, Tahsis Community Paramedic Re: Community Paramedic Program**

Good Evening Mayor, Council and staff,
Thank you for the opportunity to share information with you tonight about the Community Paramedicine in Tahsis.

My name is Josie Miladinovic, I am a Tahsis paramedic and I am the newly certified community paramedic for Tahsis and here with me tonight is my mentor Rachelle Cole, the community paramedic attached to the Uculet Station which was also 1 of 9 first prototype communities in BC over 3 years ago. We are now 1 of 99 rural and remote communities to receive a community paramedic.

Community Paramedicine is not a new concept as it has been practiced for decades in many provinces and countries around the world. However in BC we are just over 3 years into establishing our program and are 95% to capacity in our first phase as an addition to rural and remote care.

Our mandates are community education, outreach and awareness, health promotion, wellness checks and clinics. Although Community Paramedicine is in the infancy stage for our organization we already have many tools under our belts including home health monitoring and we are always expanding and updating our knowledge to include not only chronic health issues but more recently we have added palliative care training and as with all paramedics in BC mental health.
We are looking forward to an expansion of our scope to even further serve our communities in the months and years to come.
I look forward to collaborating with all the disciplines and services providers in our community along with all interest groups, stake holders and partners.
Thank you,

Fowler/Llewellyn: VOT 343/2019
THAT this presentation be received. **CARRIED**

E. Public Input # 1
Members of Ecologic Environmental Consultants introduced themselves to Mayor, Council and Staff and gave an update on the McKelvie Watershed Assessment Project.

A member of the public complained about the words used by a council member at the previous meeting.

F. Adoption of the Minutes
1 **Minutes of the Regular Council meeting held on June 18th, 2019**

Llewellyn/Elder: VOT 344/2019
THAT the Regular Council meeting minutes of June 18, 2019 adopted as presented. **CARRIED**

G. Rise and Report
None.

H. Business Arising

1 **Island Coastal Economic Trust (ICET) - Economic Infrastructure and Innovation Program (Stage 2) Grant Application**

A brief discussion followed.

Llewellyn/Fowler: VOT 345/2019

THAT this Report to Council and draft grant application be received. **CARRIED**

Fowler/Elder: VOT 346/2019

THAT Council approve the grant application as prepared by staff and submit it to ICET **CARRIED**

2 **Municipal Finance Authority of BC (MFABC) Re: Updating List of Authorized Signers**

Llewellyn/Elder: VOT 347/2019

THAT this information be received. **CARRIED**

Llewellyn/Elder VOT 348/2019

THAT Randy Taylor and Jude Schooner be removed from list "A" as signing authorities for the Village of Tahsis. **CARRIED**

Llewellyn/Elder: VOT 349/2019

THAT Mayor Martin Davis, Deputy Mayor Sarah Fowler and CAO Mark Tatchell be added to list "A" as signing authorities for the Village of Tahsis. **CARRIED**

3 **Service Provider Agreement for Climbing Wall Volunteers**

Llewellyn/Fowler: VOT 350/2019

THAT Council agree to provide liability insurance for contract volunteers who form the Climbing Wall Volunteers, through the Municipal Insurance Association's Associate Member Program;

AND THAT Council authorize the Director of Finance to enter into Service Provider Agreements with individual volunteers for the provision of liability insurance through the Village's liability insurance held with the Municipal Insurance Association of British Columbia. **CARRIED**

J. Council Reports

Mayor Davis (verbal Report)

I did attend a webinar regarding Powell River and their interactions with the community of Powell River and the local First Nations there. It was very interesting. I was looking for insight into how they work their community forests there and apparently they are two separate community forests so they have not exactly integrated them. First Nations want to buy Powell River's Community Forest. That's all I got from that.

We had a Canada Day celebration which was wonderful. I got to give a speech and hand out cake.

Councillor Elder

No report

Councillor Fowler (written Report)

My report July 2, 2019 is heavy with academic reports from scientific journals. But first, this is summer! We had our annual Canada Day Trivia Contest and sing-a-long.

It was a honour to attend the delicious dinner put together by Sally for VIHA`s Rural Site Visit Project. My big take away was that Cortes Island is doing some private care called home care plus. I think we could try to explore here. The summary of a report released February 13, 2019 read `it has been identified that relationships are a foundation part of rural health.`

Secondly, I received the following information from Uu-a-thulk fisheries program with respect to the drought conditions due to low water flow.

Please include the documents for the minutes of public record of fishery sensitive watersheds

These Pacific Northwest papers demonstrate forestry effects and ask larger questions about water demand.

Mathew Bayly of Ecofish research group, a environmental consultant with a specialist in fish habitat modeling.

`I`ve seen increasing evidence of current FRPA legislation failing to identify, monitor and manage cumulative effects to fish habitat at the watershed scale.`

	Leiner river,	Perry river,	Tahsis River
area km square	116	49	77
average elevation meter's	744	712	691
H60 Elevation meter's	860	819	838
average slope %	71.8	69.1	68.5
road density for entire FSW km	0.67	1.19	0.20
road density <100m from a stream km2	0.35	0.64	0.07
road density on slopes >60% km2	0.16	0.34	0.01
stream crossing density #/km square	2.41	5.13	0.08
portion of stream disturbed km/	0.04	0.06	0.00
portion of fish bearing streams	0	0	0

(5 attachments)

Councillor Tanner
attachments

HYDROLOGICAL PROCESSES
Hydrol. Process. (2015)
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.10726

A 477-year dendrohydrological assessment of drought severity for Tsable River, Vancouver Island, British Columbia, Canada

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Abstract:

Summer streamflow droughts are becoming more severe in many watersheds on Vancouver Island, British Columbia, as a result of climate warming. Small coastal basins that are the primary water source for most communities and essential to Pacific salmon populations have been particularly affected. Because the most extreme naturally occurring droughts are rarely captured within short instrumental records water managers likely underestimate, and are unprepared for, worst-case scenario low flows. To provide a long-term perspective on recent droughts on Vancouver Island, we developed a 477-year long dendrohydrological reconstruction of summer streamflow for Tsable River based on a network of annual tree-ring width data. A novel aspect of our study is the use of conifer trees that are energy limited by spring snowmelt timing. Explaining 63% of the instrumental streamflow variability, to our knowledge the reconstruction is the longest of its kind in British Columbia. We demonstrate that targeting the summer streamflow component derived from snowmelt is powerful for determining drought-season discharge in hybrid runoff regimes, and we suggest that this approach may be applied to small watersheds in temperate environments that are not usually conducive to dendrohydrology. Our findings suggest that since 1520, 21 droughts occurred that were more extreme than recent 'severe' events like those in 2003 and 2009. Recent droughts are therefore not anomalous relative to the ~400-year pre-instrumental record and should be anticipated within water management strategies. In coming decades, worst-case scenario natural droughts compounded by land use change and climate change could result in droughts more severe than any since 1520. The influence of the Pacific Decadal Oscillation on instrumental and modelled Tsable River summer streamflow is likely linked to the enhanced role of snowmelt in determining summer discharge during cool phases.

KEY WORDS dendrohydrology; drought; low flows; water management; Vancouver Island; British Columbia

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INTRODUCTION

British Columbia's (B.C.) temperate rainforest coast is considered water-rich, but seasonal water scarcity and streamflow drought often occur during summer when demand for water is highest and storage is limited (Stephens *et al.*, 1992). In 2014 and 2015 many streams experienced droughts that were more severe than any on record (B.C. Ministry of Forests, Lands and Natural Resource Operations, 2014; B.C. River Forecast Centre, 2015). Climate warming has triggered earlier, lower, longer, and more frequent low-flows throughout the coastal region (Rodenhuis *et al.*, 2007), and the impact of worsening droughts on human water use, stream ecology, and the survival of Pacific salmon is recognized by the provincial government as a critical environmental management challenge (B.C. Ministry of Environment, 2013).

'Hybrid' runoff regimes are the primary water source for most towns, municipalities, and First Nations communities on Vancouver Island, B.C., and are also the most vulnerable to summer water shortages (Rodenhuis *et al.*, 2007). Both snowmelt and rainfall contribute substantially to annual streamflow in hybrid watersheds (Eaton and Moore, 2010). The likelihood of protracted drought under future climate conditions makes an accurate understanding of worst-case scenario droughts, based on long-term natural variability, crucial for effective water management in these basins (Pike *et al.*, 2010).

The purpose of our research was to develop a multi-century summer discharge (Q) record for a small hybrid watershed on southeastern Vancouver Island, and to interpret the severity of recent droughts within the context of that record. We used a dendrohydrological approach, where climate-sensitive tree-ring (TR) width records serve as proxies for climate in a paleo-hydrological model (Loaiciga *et al.*, 1993). Detection of recent environmental change often requires these long-term records because natural climatic patterns, such as the Pacific Decadal Oscillation (PDO), persist over multiple decades and can obscure climate change effects (Moore *et al.*, 2007).

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While streamflow reconstructions based on TR data have been developed for drought-sensitive regions world-wide, applying traditional dendrohydrological approaches to a small hybrid watershed in a temperate environment is problematic. First, very flashy rainfall-driven runoff is often a major contributor to total annual streamflow in coastal B.C. (Eaton and Moore, 2010). Dendrohydrological models usually target annual discharge in large watersheds where both runoff and annual radial tree growth are relatively unresponsive to 'flashy' rainfall events (Pederson *et al.*, 2001; Boninsegna *et al.*, 2009; Meko and Woodhouse, 2010; Yang *et al.*, 2010; Margolis *et al.*, 2011; Sauchyn *et al.*, 2014). Second, trees on Vancouver Island are rarely moisture stressed, although the radial growth of some species is sensitive to winter precipitation as a result of the energy-limiting role of deep snowpacks (Marcinkowski *et al.*, In press). Dendrohydrological studies are usually conducted in arid environments using trees whose radial growth is limited by rainfall or snowmelt-derived soil moisture, which directly influences runoff (Woodhouse *et al.*, 2006). We circumvent these problems by targeting low-flow season streamflow in our reconstruction, a time of year when runoff is significantly less flashy, is primarily driven by snowmelt, and is most important for drought management (Smith and Laroque, 1998).

We hypothesized that summer discharge in a small hybrid basin on Vancouver Island is driven by regional snowmelt variations to the extent that TR records that are energy-limited by snow could serve as proxies for climate in a dendrohydrological reconstruction of streamflow. To date, paleohydrological efforts in B.C. have explored the utility of annual TR width and density records as proxies for winter and summer temperature and snow water equivalent (SWE) for reconstructing summer-season and mean water year runoff in nival and glacial watersheds (Gedalof *et al.*, 2004; Watson and Luckman, 2005; Hart *et al.*, 2010; Starheim *et al.*, 2013). No prior attempt has been made to develop seasonal reconstructions of the hybrid streams that are most susceptible to drought in coming decades.

We use the term 'drought' to mean streamflow drought, or below-normal stream discharge, a component of hydrological drought that often also coincides with reduced groundwater availability (Van Loon and Laaha, 2015). Consistent with B.C. government management practices, 'drought' refers to below-normal stream runoff persisting over a period of consecutive months (B.C. Ministry of Environment, 2013).

RESEARCH BACKGROUND

Large precipitation and temperature gradients characterize most watersheds on Vancouver Island. Winter storms originating in the North Pacific Ocean bring moisture to the west coast of the island, where orographic lift results in deep snowpacks at high elevation and large quantities of rain in lowland areas (Stahl *et al.*, 2006). Rain shadow effects on the east side of Vancouver Island result in drier conditions in lowland coastal regions (Rodenhuis *et al.*, 2007). Summers are warm and dry, and dominated by persistent high-pressure systems (Rodenhuis *et al.*, 2007). Seasonal hydroclimatic patterns are moderated by synoptic-scale inter-annual and decadal modes of climate variability stemming from ocean–atmosphere interactions in the Pacific Basin, of which the PDO, the El Niño Southern Oscillation (ENSO), and the Pacific North America (PNA) pattern have a particular influence on regional streamflow (Kiffney *et al.*, 2002).

Hybrid streams on Vancouver Island are found primarily in mid-elevation coastal and near-coastal areas where mean watershed elevations are not high enough to be fully nival (Eaton and Moore, 2010). Hybrid streams experience highest mean monthly flows during winter rains, followed by a significant pulse of runoff from snowmelt in spring. Lowest monthly flows occur during summer when discharge is governed by snow meltwater inputs, nominal summer precipitation inputs, and losses related to high summer air temperatures and evaporation (Eaton and Moore, 2010). Snowmelt can significantly recharge deep groundwater flow pathways to augment summer baseflow in the study region, even if only a small snow fed headwater is present (Moore *et al.*, 2007; Beaulieu *et al.*, 2012). Above average minimum summer discharge is therefore often coincident with deep snowpacks that develop during cool and wet La Niña years, especially when enhanced by cold phases of the PDO (Fleming *et al.*, 2007). The proportion of rainfall-derived *versus* snowmelt-derived runoff varies from year to year in accordance with fluctuations in winter temperature, so that annual flows in hybrid regimes can be 'more pluvial' or 'more nival' in any given year (Moore *et al.*, 2007). A high between-year range in monthly flow totals is typical (Moore *et al.*, 2007).

In the south coastal region of B.C., annual minimum streamflow has decreased in hybrid watersheds over the last 30 years, with low-flow magnitudes projected to decline by up to 50% by the end of the century as a result of seasonal climate trends (Rodenhuis *et al.*, 2007; Mantua *et al.*, 2010). Winters have become milder and wetter, with less winter precipitation falling as snow and more as rain, and more frequent rain-on-snow events. As a result, less snow meltwater is available to buffer low stream discharge during the dry summer months (Pike *et al.*, 2010). Projections suggest that nival flow contributions will weaken or become non-existent, eventually shifting many hybrid systems to more pluvial regimes (Eaton and Moore, 2010). Summers have become warmer and drier additionally drawing-down summer flows (Pike *et al.*, 2010).

STUDY SITE

The Tsable River watershed is a small (113 km^2) hybrid basin located on the eastern slopes of the Beaufort Range on central Vancouver Island, in the rainshadow of the Vancouver Island Ranges (Figure 1). With a maximum basin elevation of around 1500 m asl, a significant portion of precipitation within the watershed falls as snow above 1000 m asl (Eaton and Moore, 2010). Tsable Lake (~1 km^2) and several smaller lakes are located with the basin. Draining east to the Strait of Georgia, the lower reaches of the watershed are located within the dry Coastal Douglas Fir Zone, transitioning from the Coastal Western Hemlock Zone, to the Mountain Hemlock Zone and Alpine Tundra Zone with increasing elevation (Klinka *et al.*, 1991). At high elevation (1000–1500 m asl) the growing season is short and cool, with very deep snowpacks often persisting into the spring and summer. Mountain hemlock (TM; *Tsuga mertensiana* (Bong.) Carrière) trees are dominant, with subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and amabilis fir (AA; *Abies amabilis* (Doug.) ex. Louden) trees occasionally co-dominant. Industrial logging is the main land use in the watershed.

Highest total monthly discharge in Tsable River occurs from November through January, with spring snowmelt causing a distinct pulse of runoff in May (Figure 2; Eaton and Moore 2010). Analysis of annual hydrographs provides a comparison between years dominated by winter rainfall- *versus* summer snowmelt-derived runoff (Figure 2). Lowest flows occur in July through September (Figure 2). In recent years, Tsable River summer baseflow has been far below optimum for the river's populations of chum, coho, and pink salmon, and resident and anadromous steelhead and cutthroat trout (B.C. Conservation Foundation 2006). Despite conservation efforts, low-flows have degraded stream habitat to the extent that the wild steelhead stock has likely been extirpated since the early 2000s (Lill, 2002; Silvestri, 2004).

DATA AND METHODS

Hydrometric and climate data

Only three hybrid streams on Vancouver Island have >50 years of natural and continuous instrumental data. Tsable River was selected for this study because it is the hybrid stream with the longest continuous natural hydrometric record (1960–2009), and the watershed does not contain large natural water storage features such as lakes and wetlands. We downloaded monthly discharge data for Tsable River from the Water Survey of Canada (http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm). Missing values (1% of the data) were replaced with long-term monthly means (station code 08HB024; gauge location latitude: 49.517, longitude: −124.841, elevation: 1 m asl). We used the average flow from July to August for our reconstruction because the regional hydrological literature suggests that stream discharge is significantly correlated with previous winter SWE during that season (Rodenhuis *et al.*, 2007; Eaton and Moore, 2010). The July–August streamflow data, hereinafter 'summer

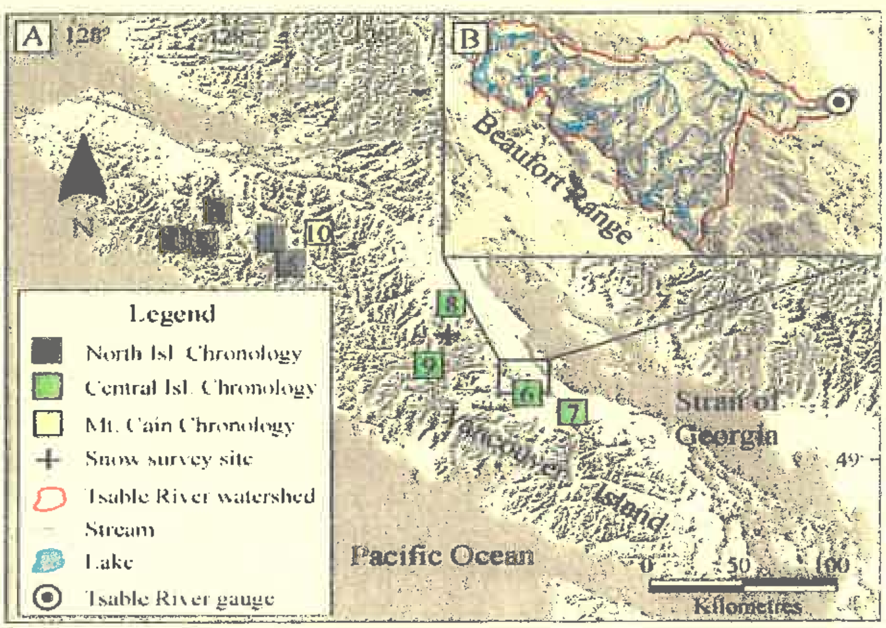

Figure 1. Map of the study area. (A) Vancouver Island. (B) Tsable River watershed 263 × 186 mm

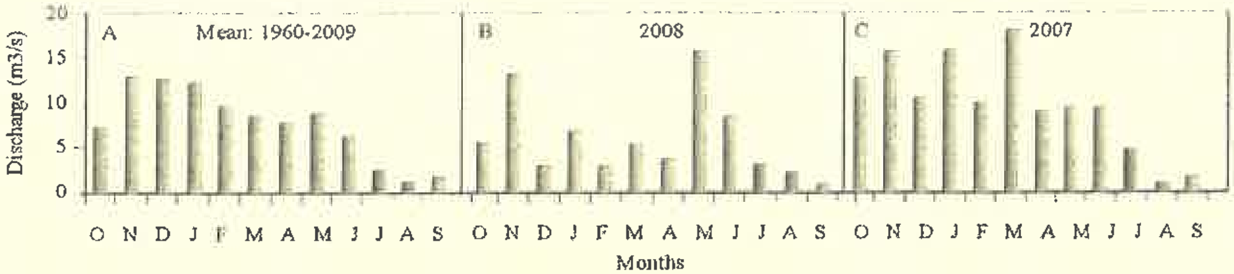

Figure 2. Tsable River water-year hydrographs. Dark bars indicate the reconstruction season (July–August). (A) Gauged mean monthly discharge over the length of record used (1960–2009); (B) mean monthly discharge in a 'more nival' year when runoff during spring snowmelt outweighed rain-derived runoff during winter; (C) mean monthly discharge in a 'more pluvial' year when runoff from winter rains outweighed runoff from spring snowmelt

streamflow' data, span the interval 1960–2009 and were normalized using a log10 transformation.

May 1 SWE records collected at the Forbidden Plateau manual snow survey site (data period February–May 1958–2014; station code 03B01; latitude: 49.653, longitude: −125.207, elevation: 1100 m asl) were retrieved from the Water Survey of Canada (http://a100.gov.bc.ca/pub/mss/stationdata.do?station=3B01). May 1 is generally the maximum annual SWE measurement in the Forbidden Plateau dataset. We estimated monthly maximum temperature and total precipitation anomaly records on the coordinates of the Tsable River hydrometric gauge site using the programme ClimateWNA, ver. 4.83 (Wang *et al.*, 2006; 2012). The programme downscales PRISM (Daly *et al.*, 2002) monthly data (2.5 × 2.5 arc min) based on the reference period 1961–1990. We compared the gauged and reconstructed streamflow records with NOAA Multivariate ENSO Index ranks (http://www.esrl.noaa.gov/psd/enso/mei/) and standardized values of the PDO index downloaded from the NOAA Earth System Research Laboratory website (http://www.esrl.noaa.gov/psd/data/climate indices/list/). Winter (averaged October–March) PDO data were used because year-to-year variability in the index is most energetic during those months (Mantua, 2002).

Tree-ring data

Mountain hemlock and amabilis fir TR width data were used for this study. In the northwestern United States and Canada, the annual radial growth of high-elevation conifer trees is often energy limited as a result of variations in snowpack depth (Peterson and Peterson, 1994). Snow may control the timing of the start or end of the growing season and, therefore, total growing season length through its influence on soil temperatures, which warm rapidly after snowmelt (Graumlich and Brubaker 1986). This climate-radial tree growth relationship is well-documented in mountain hemlock trees (Graumlich and Brubaker, 1986; Smith and Laroque, 1998; Laroque and Smith, 1999; Gedalof and Smith, 2001a; Peterson and Peterson, 2001; Zhang and Hebda, 2004; Marcinkowski *et al.*, In press) and field observations suggest amabilis fir trees typically initiate leaf and shoot expansion shortly after snowmelt (Worrall, 1983; Hansen-Bristow, 1986).

TR width data was compiled for one amabilis fir stand and eight mountain hemlock stands located on central and northern Vancouver Island (Figure 1, Table I). These data were selected because they provided the longest potentially SWE-sensitive TR width records. Crossdated amabilis fir TR width measurements collected by R. Parish at Mt. Cain in 1999 were acquired from the International Tree-Ring Data Bank website (http://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/tree-ring). Mountain hemlock samples were collected between 1996 and 1998 by removing two cores with a 5.0-mm increment borer from trees at standard breast height. Ring widths were measured using WinDENDRO Ver 6.1b (WinDENDRO, 1996; Laroque, 2002). In 2014, the measurements were crossdated visually (list method) and statistically verified using the programme COFECHA 3.0 (Holmes, 1983; Grissino-Mayer, 2001). In some cases physical samples were missing from the archived collections. Because crossdating was not possible without physical specimens, only a subset of the original samples could be used for each site. As a result, sample sizes per site were very low in some cases (Table I).

Tree-ring chronologies were developed using the R package dplR (Bunn, 2008). We removed long-term biological growth trend from the TR data by fitting a 100-year cubic smoothing spline with a frequency cutoff of 50 to each TR series (Cook and Peters, 1981). Dimensionless growth indices were produced by dividing ring-width measurements by the expected value of the spline. The majority of the TR data exhibited low-order autocorrelation as a result of the lagged influenced of environmental conditions in previous years (Fritts, 1976). We fit an autoregressive model to the data to remove persistence, with the model order defined by minimization of the Akaike Information Criterion. Only residual

Table I. Tree-ring chronology information. Chronologies in bold font were entered as candidate predictors in the forward stepwise model

Chronology	#	Lat/Long	Elev (m asl)	RBAR[c]	Length (years)	Series (#)	Trees (#)	r_1[d]
Bulldog Ridge[a]	1	50.28 −127.24	1010	0.22	1845–1997	9	6	0.72
Castle Mountain[a]	2	50.45 −127.12	1150	0.32	1845–1997	10	7	0.75
Colonial Creek[a]	3	50.28 −127.46	990	0.29	1940–1997	7	5	0.76
Silver Spoon[a]	4	49.98 −126.67	1100	0.37	1955–1996	11	8	0.66
N. Isl. Regional[a]		—	—	**0.26**	**1630–1997**	**37**	**28**	**0.72**
Mt. Apps[a]	5	49.44 −124.96	1340	0.29	1795–1996	40	22	0.63
Mt. Arrowsmith[a]	6	49.24 −124.59	1460	0.33	1575–1997	11	8	0.72
Mt. Washington[a]	7	49.75 −125.30	1470	0.42	1795–1996	15	12	0.68
Cream Lake[a]	8	49.48 −125.53	1340	0.36	1525–1995	29	18	0.68
C. Isl. Regional[a]		—	—	**0.30**	**1510–1997**	**95**	**61**	**0.68**
Mt. Cain[b]	**9**	**50.22 −126.35**	**1005**	**0.31**	**1520–1999**	**64**	**34**	**0.83**

[a] Mountain hemlock.
[b] Amabilis fir.
[c] Mean correlation coefficient among TR series, calculated from the detrended residual chronology.
[d] Mean first-order autocorrelation calculated using programme COFECHA, prior to autoregressive modelling.

chronologies estimated by this procedure were used in the subsequent analysis (Cook and Holmes, 1986). Series were combined into single representative 'site-level' chronologies using a bi-weight robust mean estimation (Mosteller and Tukey, 1977). Where two or more series were included from one tree, we averaged them prior to mean chronology estimation in order to weight individual trees equally. We determined the adequacy of the sample size for capturing the hypothetical population growth signal by calculating the expressed population signal (EPS; Wigley *et al.*, 1984), and truncated the chronologies where EPS < 0.80. Because of the low number of samples per site, we aggregated the records into regional chronologies where site-level chronologies were significantly intercorrelated. This significantly extended the lengths of our TR records by enhancing signal-to-noise ratios in the early part of the record. The methods used to estimate site-level chronologies were also used to estimate regional chronologies.

The Pearson correlation coefficient was used to summarize the strength of linear relationships between various time series in this study. All tests of association were conducted over the longest common interval between datasets. We used correlation tests to determine whether the site-level and regional TR chronologies were significantly linearly correlated with the gauged summer streamflow data, with Bonferroni corrections applied for repeated testing (Dunn 1961). The temporal stability of relationships in non-overlapping data subperiods was tested using a difference-of-correlations test that employs a Fisher's Z transformation of correlations (Snedecor and Cochran, 1989). Long chronologies that were significantly ($p < 0.01$) correlated with summer streamflow over the full length of the streamflow record were retained as candidate model predictors.

Hydroclimate relationships

To determine the climatic variables controlling summer discharge in Tsable River, and to justify a SWE-based reconstruction model of the river, we tested correlations of the gauged summer streamflow data with various monthly and seasonal climate data records. Effective sample sizes (Dawdy and Matalas, 1964) were used as needed in testing the correlations for significance, to adjust for persistence in the individual time series.

To assess the influence of snow on runoff, we tested the correlation of gauged summer streamflow data with current and previous year May 1 SWE values. We applied the previously described difference-of-correlations test (Snedecor and Cochran, 1989) to determine if there is a significant change in the relationship between streamflow and SWE before and after the 1976/77 PDO shift (Mantua, 2002). Because high summer streamflow is usually associated with enhanced snowmelt in hybrid streams (Eaton and Moore, 2010), we checked that low summer streamflow years are also influenced by meltwater by sorting the gauged summer streamflow data into lowest, middle, and highest terciles, and calculating Pearson's correlations between the summer streamflow and May 1 SWE values within each tercile.

Correlations of gauged summer runoff with monthly and seasonally aggregated temperature and precipitation data were calculated using the programme Seascorr (Meko *et al.*, 2011). Seascorr estimates confidence intervals on the sample correlations and partial correlations by a Monte Carlo simulation of the flow data by exact simulation (Meko *et al.*, 2011). Correlations of the gauged summer streamflow data with maximum temperature data were tested in 1- to 6-month intervals, with intervals ending in each month of the 14-month period beginning in July of the previous year and ending in August of the current year. Partial correlations were then calculated to determine if annual, and especially summer, precipitation makes a significant contribution to summer runoff that is independent of the temperature influence. We also tested monthly and seasonal correlations between the temperature and precipitation data in the same seasonal and monthly groupings. Relationships to climate in the previous year were evaluated because we were curious whether they influence current-year summer runoff as a result of hydrological lag effects in the groundwater system.

Model estimation

The reconstruction model was estimated by forward stepwise multiple linear regression of the summer streamflow data in year t on the pool of candidate predictor variables in years t, $t+1$, and $t+2$. Lagged predictors were entered to allow TR information in subsequent years to inform on climate conditions in the given year (Cook and Kairiūkštis, 1990). We evaluated regression models based on a suite of statistics widely used to evaluate tree-ring based environmental reconstructions. The adjusted R^2 statistic provides a measure of the explanatory power of the models accounting for lost degrees of freedom. Analysis of the model residuals, and the Durbin–Watson (D–W) and variance inflation factor (VIF) statistics, were used to check the model fit and assumptions. The F-ratio gives an estimate of the statistical significance of the regression equation and the standard error of the estimate (SE) a measure of uncertainty of the predicted values of the model calibration. We used leave-one-out (LOO) cross-validation (Michaelsen, 1987) to validate the models against data that were not used in the calibration. This approach allowed us to use the full 37 years of corresponding streamflow and TR data for the validation procedure, which was important given the relatively short calibration interval. We calculated cross-validation statistics by comparing the predictand gauged summer streamflow data with the LOO-estimated values of the predictand. The reduction of error (RE; Fritts *et al.*, 1990) provides a rigorous measure of model skill, with a positive value indicating that the LOO estimates better predict instrumental flow data than the mean of the instrumental data. The root mean square error of cross-validation ($RMSE_v$) gives a measure of the uncertainty of the predicted values over the verification period. The Pearson correlation (r) and R^2 of the observed and LOO-estimated values provide additional measures of accuracy (Cook and Kairiūkštis, 1990). The best model was calibrated over the full instrumental streamflow data record and used to reconstruct historical summer streamflow over the length of the shortest predictor dataset. We back-transformed the reconstructed values (modelled from TRs) to the original flow units for plotting and analysis, and checked that the selected model predictors are linearly correlated with the reconstructed flow data over the full instrumental data interval. To confirm that they operate as proxies for climate in our paleohydrological model we tested whether the model predictors are correlated with May 1 SWE and/or spring/summer maximum temperature. Correlations with temperature were calculated with Seascorr using the procedure described for hydroclimate correlations.

Analysis of the reconstruction

We compared statistical properties of the reconstructed record in the separate pre-instrumental (1520–1959) and instrumental (1960–1997) periods, with those of the gauged summer streamflow data. This comparison allowed us to determine if the pre-instrumental reconstructed record differs from reconstructed record during the instrumental era in any significant way, and also allowed us to assess the capacity of our model to approximate statistical characteristics of actual Tsable River summer streamflow. Extreme single-year droughts were defined based on a bottom fifth percentile threshold of summer streamflow, calculated based on the full reconstruction data period (1520–1997). Drought timing and magnitudes were then plotted as departures from the reconstructed mean summer streamflow calculated from the instrumental period. Comparing reconstructed values in the pre-instrumental and instrumental periods puts extreme historical droughts in the context of recent conditions without making unequal comparisons between TR-modelled streamflow data and gauged streamflow data.

We calculated the return interval of extreme droughts following the equation of Mays (2005) and used Chi-squared analysis to test if the frequency of these events in the gauged summer streamflow record (1960–2009) differed from an expected frequency of five events per 100 years (bottom fifth percentile). High year-to-year summer discharge variance is typical in hybrid watersheds and can make it difficult to identify multi-year stretches of generally low runoff, so we assessed the number of years of below median runoff over a sliding 21- year window. To determine whether reduced summer runoff corresponds with enhanced overall runoff variance, we visually compared extreme drought timing and intervals of generally low discharge with a sliding 21-year average of the standard deviations of the reconstructed summer streamflow values.

The gauged and reconstructed summer streamflow records were compared with instrumental ENSO and PDO records to investigate the influence of large-scale climate modes on droughts and wet episodes. A test of proportions (Newcombe, 1998) was used to determine if the proportion of years with below-median (or above-median) runoff during El Niño years equals the proportion of years with below-median (or above-median) runoff during weak- and non-El Niño years. The strength of El Niño/La Niña in a given year was based on NOAA Multivariate ENSO Index ranks. The same difference-of-correlations test (Snedecor and Cochran, 1989) was used to determine if correlations of the winter PDO data with the gauged and reconstructed streamflow records are significantly different during cool *versus* warm PDO phases. Effective sample sizes (Dawdy and Matalas, 1964) were used as needed to account for autocorrelation in the individual time series. A Morlet wavelet analysis (Torrence and Compo, 1998) was performed on the full reconstructed record to highlight localized fluctuations of power over time that may be associated with climate modes.

RESULTS

Tree-ring data

We developed eight site-level mountain hemlock chronologies and one site-level amabilis fir chronology for this study (Table I). Four significantly intercorrelated (mean $r = 0.753$, $p < 0.01$) mountain hemlock chronologies were combined into a regional chronology representing northern Vancouver Island, and four significantly intercorrelated (mean $r = 0.841$, $p < 0.01$) mountain hemlock chronologies were combined into a regional chronology representing the central part of Vancouver Island. Consolidating short site-level chronologies enhanced chronology sample depths to the extent that the regional chronologies could be used for dendroclimatic reconstruction. Chronology lengths for the final chronologies ranged from 367 to 487 years and mean correlation coefficient among TR series (RBAR) ranged from $r = 0.26$ to 0.31 (Table I). All chronologies were significantly ($p < 0.01$) correlated with the gauged summer streamflow data (r ranging from 0.466 to 0.867). The two regional chronologies and the Mount Cain amabilis fir chronology were retained as candidate model predictors.

Hydroclimate relationships

Of the monthly and seasonal climate data tested, the Tsable River gauged summer streamflow data are most strongly correlated with current-year May 1 SWE (Table II), a positive relationship that is stable over the over the 1976/1977 PDO shift (Mantua, 2002). This relationship is also significant ($p < 0.05$) in the lower and upper, but not middle, terciles of the gauged data (lower tercile: $n = 17$, $r = 0.529$, upper tercile: $n = 17$, $r = 0.552$). The gauged data are also negatively correlated with maximum temperature in March through August of the current year (Table II, Figure 3) and, independently, with winter precipitation but not summer precipitation (Figure 3). No relationships to climate in the previous year were significant. Panel B in Figure 3 indicates that temperature and precipitation data are significantly negatively correlated in July through October and May through August.

Model estimation and reconstruction

A reconstruction that used the central island regional chronology in time t and Mt. Cain amabilis fir chronology in time t was selected as the best model

$$Q = 2.05 - (0.993 * \mathit{central\ island\ TRs}) - (0.527 * \mathit{Mt.\ Cain\ TRs})$$

Time plots of the chronologies are presented in Figure 4. Despite similarities between the predictors, the standardized coefficients indicate that the amabilis fir chronology contributes significant additional explanatory power to the model (beta = −0.33) relative to the central island chronology (beta = −0.60). The reconstructed record spans 1520–1997 and explains 63% of the variance in the gauged Tsable River summer streamflow data (1960–2009) accounting for lost degrees of freedom. The reconstructed and the gauged streamflow data are compared in original streamflow units in Figure 5A. Regression and cross-validation statistics are summarized in Table III, and a time plot of

Table II. Hydroclimate correlations

	Central Isl. TM	Mt. Cain AA	SWE	Max T
Q (JA)	−0.75	−0.61	May 0.70	Mar–Aug −0.61
Central Isl. TM	—	0.46	May −0.58	Mar–Apr 0.41
Mt. Cain AA		—	May −0.53	Jul–Aug −0.36

Current year in capital letters.
For all correlations $p < 0.01$.

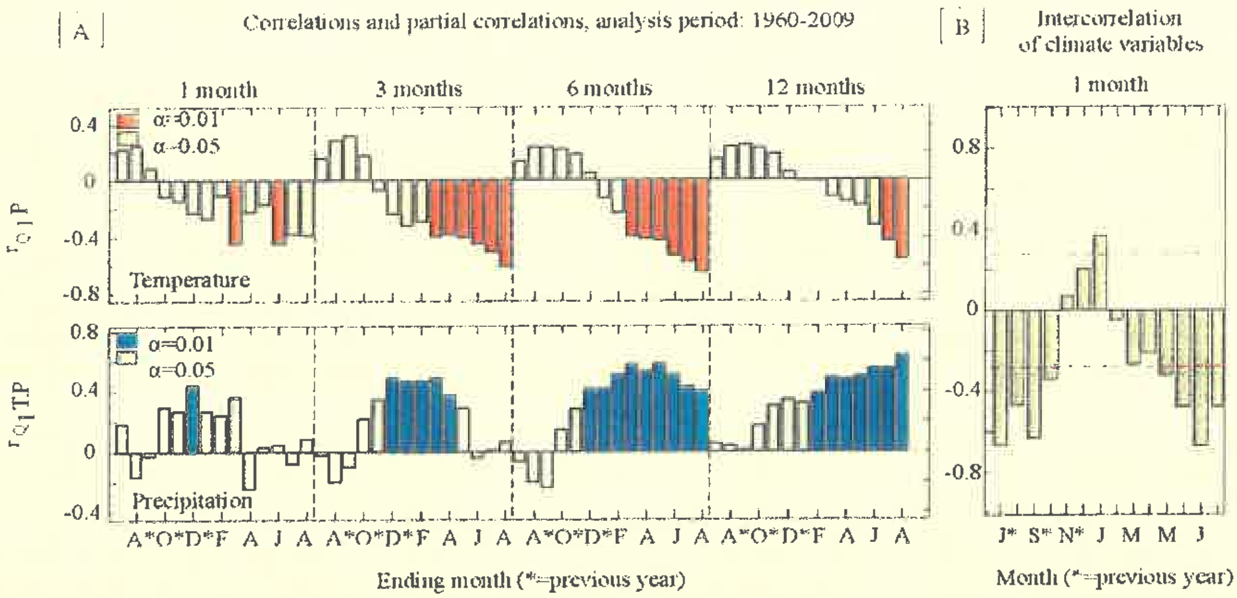

Figure 3. (A) Monthly and seasonal correlations between Tsable River July–August streamflow (Q) and maximum temperature, over 1-, 3-, 6-, and 12-month sliding windows beginning in the previous July through current August (top), and; monthly and seasonal partial correlations between Tsable River flows and precipitation, controlling for the influence of maximum temperature. (B) Monthly correlations between temperature and precipitation, beginning in the previous July through current August. Red-hatched bands represent 95% confidence intervals with the confidence interval set at $0 + 1.96/\sqrt{N}$, where N is the sample size. All tests were calculated using Seascorr

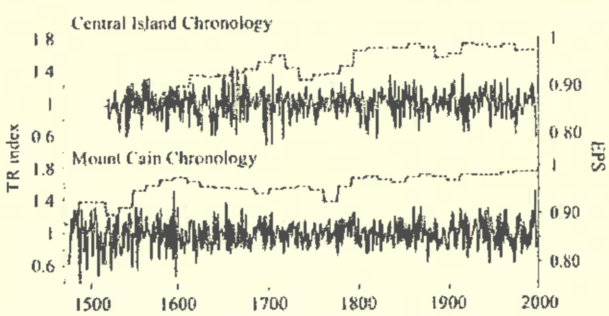

Figure 4. Time plot of tree-ring chronologies used as model predictors. EPS values are plotted with a hatched line

the cross validation is presented in Figure 5B. Collinearity diagnostics indicate that predictors are adequately independent, and the F-ratio indicates a statistically significant regression equation. The positive RE value is very similar to the validation R^2, and the SE value approximates that of the $RMSE_v$, suggesting a well-validated model. The LOO-generated predicted values of the predictand are significantly and strongly ($r = 0.62$, $p < 0.01$) correlated with the gauged summer streamflow data. Analysis of regression residuals indicated that the models do not violate regression assumptions. The chronologies are significantly ($p < 0.01$) correlated with the gauged summer streamflow data over the full period of that record (Figure 5C, Table II).

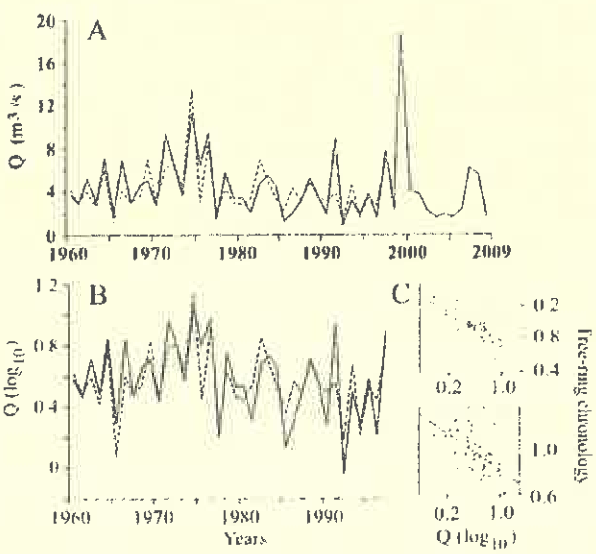

Figure 5. (A) Time plot of the reconstructed (hatched line) and gauged (solid line) summer streamflow data, backtransformed to original flow units, over the model calibration period. The instrumental data extend to 2009. (B) Time plot of the cross validation. The solid line represents the gauged (transformed) streamflow data, and the hatched line represents the LOO estimates. (C) Scatterplots of the linear associations of the central island regional chronology (above: $R^2 = -0.565$) and the Mount Cain chronology (below: $R^2 = -0.373$) with the predictand streamflow data

The central island regional chronology is most strongly negatively correlated with May 1 SWE, and is also weakly positively correlated with maximum temperature

Table III. Reconstruction and cross-validation statistics

Adj. R^2	D–W	VIF	SE	F-ratio[a]	RE	$RMSE_v$[b]	r[c]	R^2[d]
0.63	2.08	1.27	0.16	32.86	0.62	0.16	0.79	0.62

[a] Significant at the 99% level.
[b] Derived from transformed flow (unitless).
[c] Cross-validation r ($p < 0.01$).
[d] Cross-validation R^2.

in March through April (Table II). The Mt. Cain amabilis fir chronology is most strongly negatively correlated with May 1 SWE, and also exhibits a weaker negative correlation with maximum temperature during July and August (Table II, Figure 4).

Analysis of the reconstruction

The cross-validation time plot exhibits strong coherence between the gauged summer streamflow data and the LOO-estimated values (Figure 5B). While the magnitudes of both high and low flows are over and underestimated at times (for example, the magnitudes of the three lowest flows are underestimated), the modelled data track the instrumental data well overall.

Generally, our reconstruction describes very high year-to-year variance typical of a small hybrid streamflow regime that shifts intermittently from more pluvial to more nival states, and where variance is not smoothed by hydrological lag over multiple years (Figure 6). Autocorrelation function plots indicate that neither the gauged or reconstructed summer streamflow data are significantly autocorrelated at lags <15 years. Generally symmetric high-to-low flow variance is punctuated by intervals of enhanced variance driven by high flows (Figure 6). While the mean summer streamflow values and standard variances are similar in the gauged and reconstructed records, the gauged minimum/maximum values are slightly lower/higher than the reconstructed values (Table IV). A scatterplot of the standardized residual values against the gauged summer streamflow data, as well as the width of the reconstruction confidence intervals (Figure 6) suggest that our model most accurately estimates summer streamflow values in low flow years and may underestimate them in high flow years.

The timing and magnitudes of bottom fifth percentile flow years ($Q < 1.67\,m^3/s$) are plotted in Figure 6. Twenty-two extreme droughts occurred prior to the instrumental record, with a 20 year return interval (Figure 6, Table V). The most extreme droughts recorded occurred in 1651, 1660, and 1665, with an unusual cluster of seven drought years occurring between 1649 and 1667. Only once in the last 440 years have drought conditions persisted for three or more years (1665–1667). None of the reconstructed droughts was more severe than the worst instrumental drought in 1992, when summer streamflow was only 21% of the reconstructed instrumental period mean discharge (Table V).

Table IV. Gauged and reconstructed streamflow statistics

Streamflow data	min (m^3/s)	mean (m^3/s)	max (m^3/s)	cv[a]	r_1[b]
Gauged	0.9	4.4	18.6	0.53	−0.11
Reconstructed (instrumental period)	1.3	4.2	13.4	0.69	−0.12
Reconstructed (pre-instrumental period)	0.7	4.1	13.3	0.54	−0.11

[a] Coefficient of variation.
[b] First-order autocorrelation coefficient. None significant ($p < 0.05$) for lags 1–15.

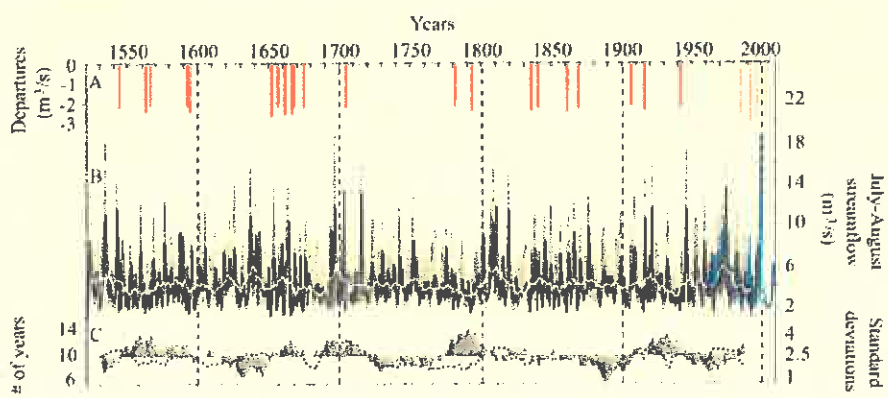

Figure 6. (A) Extreme droughts, plotted as departures from the reconstructed instrumental period mean. Reconstructed droughts are represented with red bars and gauged droughts with red hatched bars. The gauged drought magnitudes are calculated from a threshold derived from the reconstructed record. (B) Time plot of reconstructed Tsable River July–August streamflow (black line) with 5-year running mean (white line), gauged streamflow data (blue line), and 95% confidence intervals calculated from the RMSEv (Weisberg 1985; grey envelope). (C) Line graph of the number of years when July–August streamflow fell below the median value of the full-period reconstruction, plotted over a 21-year sliding window (grey fill) and a sliding 21-year average of the standard deviations of the reconstructed streamflow data (dotted line). For both the median departures and standard deviations, each plotted value represents the central value of the sliding window

Table V. Pre-instrumental bottom fifth percentile low-flow timing and magnitudes (regular font), and gauged flows falling below the reconstructed bottom fifth percentile threshold (bold font). Presented in order of severity

Year	Departure[a] (m^3/s)	Mean July–August flow (m^3/s)	% of reconstructed instrumental period mean Q
1992	**−3.33**	**0.91**	**21**
1651	−3.21	1.03	23
1660	−3.14	1.10	25
1665	−3.11	1.13	26
1860	−2.98	1.30	29
1593	−2.93	1.31	30
1792	−2.92	1.32	30
1834	−2.91	1.33	30
1915	−2.89	1.35	31
1985	**−2.86**	**1.38**	**31**
1562	−2.88	1.40	32
1941	−2.81	1.43	32
1868	−2.76	1.48	33
1839	−2.75	1.49	34
1704	−2.70	1.54	35
1674	−2.69	1.55	35
1780	−2.66	1.58	36
1543	−2.65	1.59	36
1655	−2.65	1.59	36
1977	**−2.65**	**1.59**	**36**
1666	−2.62	1.62	37
1667	−2.62	1.62	37
1905	−2.60	1.64	37
1565	−2.58	1.66	38
1591	−2.58	1.66	38
1996	**−2.58**	**1.66**	**38**
2003	**−2.58**	**1.66**	**38**

[a] Departure from the reconstructed instrumental period mean (4.24 m^3/s).

Gauged summer streamflow values also fell below the bottom fifth percentile threshold in five years (1977, 1985, 1992, 1996, and 2003; Figure 6, Table V). The Chi-squared analysis indicated that the frequency of extreme droughts in the gauged record does not differ from the expected frequency (Chi-squared $=4.69$, $p=0.10$). We have reported the magnitudes of extreme instrumental droughts in terms of their departure from the reconstruction mean over the instrumental period which is a slightly unequal comparison because the instrumental period was omitted from the calculation of the bottom fifth percentile threshold.

The number of years where summer streamflow fell below the median value of the full-period reconstruction is plotted over a 21-year sliding window in Figure 6. Each value in Figure 6 represents the central value of the sliding window. The plot makes it possible to identify periods of time when summer streamflow was either high or low overall relative to the median, despite the very high year-to-year variance dominating the reconstruction. Periods of overall lower flows occurred from the mid-1560s to late 1500s, 1650–1720, 1770–1810, and 1905–1941. Visual comparison of these periods with intervals of higher year-to-year summer streamflow variance, highlighted in Figure 6 by the sliding-mean standard deviations, does not suggest any relationship of generally higher/lower summer streamflow with higher overall variance.

Neither the gauged or reconstructed summer streamflow records exhibited differences in the number of below (above)-median flows during El Niño *versus* weak- and non-El Niño years (Table VI). Both records were significantly correlated with winter PDO over the full common data interval ($r=-0.47$ and $r=-0.23$ respectively, $p<0.01$), although the reconstructed record exhibited a weaker relationship. Relationships with winter PDO were stronger during the early/cool phase (1960–1976; $r=-0.57$ and $r=-0.47$ respectively, $p<0.01$) than the late/warm phase (1977–1997; $r=-0.30$ and $r=-0.11$ respectively, $p<0.01$), but the difference between correlations in these periods was not statistically significant for either record. The wavelet power spectrum identifies repeating, but not necessarily regular, fluctuations (energy) in the time series over time (Torrence and Compo, 1998). The reconstructed streamflow data (Figure 7) exhibits significant ($p<0.01$) energy in the approximately 2, 4, and 8-year bands that is intermittent over time, and energy in the approximately 15–30 year band that is more persistent over time, including throughout the mid- 1600s, 1800–1850, and 1960–1980.

Table VI. Test of proportions determining associations of instrumental and reconstructed flow data to El Niño events, calculated over the period 1960–1997. Calculated using function *prop.test* in R. Proportions of years in each streamflow category noted in parentheses. The null hypothesis that both groups have the same true proportions was true for all tests, with p values ranging around 0.32 (average)

Streamflow category	# El Niño years	# non-El Niño years	# El Niño and non-El Niño years
Instrumental flow data			
Below median	9 (40.9%)	10 (62.5%)	19 (50%)
Above median	13 (59.1%)	6 (37.5%)	19 (50%)
Total	22 (100%)	16 (100%)	38 (100%)
Reconstructed flow data			
Below median	8 (36.4%)	11 (68.7%)	19 (50%)
Above median	14 (63.6%)	5 (31.3%)	19 (50%)
Total	22 (100%)	16 (100%)	38 (100%)

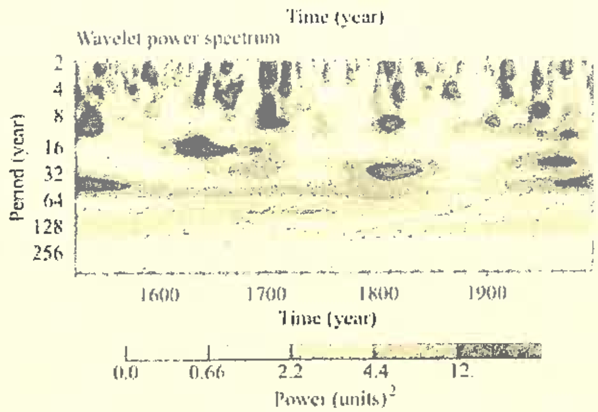

Figure 7. Morlet wavelet power spectrum on the full reconstructed streamflow record. The black contours represent the 95% confidence level based on a white-noise background spectrum. The hatched area represents areas of the spectrum susceptible to the effects of zero padding (Torrence and Compo 1998)

DISCUSSION

Reconstruction model

Our reconstruction effectively estimates July-August streamflow in Tsable River based on two TR-derived proxy records sensitive to regional-scale SWE variability. Correlation analyses indicate that runoff during this season is driven principally by snowmelt, and that the selected TR predictors primarily operate as proxies for that streamflow component in our paleohydrological model. The sensitivity of gauged summer streamflow data to previous winter SWE and spring/summer maximum temperatures supports the interpretation that Tsable River is characterized by a hybrid hydrological regime. Tercile correlations confirm that low streamflow values, not just high streamflow values, are influenced by snowmelt. The gauged streamflow record is also influenced by summer temperature fluctuations which can impact runoff because of the large relative influence of evaporation on small basins (Margolis *et al.*, 2011). Some temperature-related variability may be incorporated into the reconstruction because the two predictor TR chronologies are influenced by temperature in the spring and summer, respectively. The model residuals are correlated with maximum temperature during March (-0.42, $p < 0.01$) but not during summer months, suggesting summer temperature related variability from the Mount Cain TR chronology may influence the model estimates. The negative relationship between TRs and summer temperature means that summer temperature information within the TR chronology serves to weaken the relationship between TRs and streamflow, which may reduce model accuracy (although the TR-temperature relationship is notably weak; $r = -0.36$, $p < 0.01$). Finally, the instrumental streamflow data are influenced by winter rainfall persisting in the groundwater system, and summer rainfall. Neither of these flow components is captured by our model but, because they contribute little to summer runoff, it is not likely this seriously reduces the accuracy of the reconstruction. A possible limitation of our reconstruction is that cross-validation statistics can be biased upward when the cross-validation period is short (Meko, 2006), although the cross-validation time plot indicates a strong model validation.

Our reconstruction is primarily 'tuned' to SWE-driven runoff variations. However, we found that the gauged summer streamflow data are also influenced by spring/summer maximum temperature. The inability of our model to fully capture temperature-driven summer streamflow variability likely contributes to general underestimation of the severity of the lowest gauged flows (3/4 lowest instrumental flow values are underestimated), although low flows are still more precisely estimated than high flows. The incorporation of a summer temperature-sensitive proxy in a similar model may improve the accuracy of low-flow magnitude estimations and, given the non-independence of temperature and precipitation fluctuations during summer, might also enable a model to account for some portion of variability in summer precipitation.

As is typical in TR-based regression, our model does not capture the full range of instrumental streamflow variance (Table IV; Cook and Kairiūkštis, 1990). We emphasize that as a result, the reconstruction likely underestimates the severity of historical lowest summer flows. For example, although the model residuals suggest low flows are generally more accurately estimated than high flows, the magnitudes of the three worst instrumental droughts are all underestimated in the cross-validated and reconstructed data (Figure 5A, B). We have also reconstructed mean, not minimum, July–August streamflow values; actual lowest streamflow values would be lower than those estimated by our model.

Extreme droughts

Twenty-two extreme droughts occurred over the 439-year pre-instrumental record. As a modern analogue, the low-flow magnitudes in all but one of these years were more severe than the gauged values in 2003 and 2009 when severe summer drought throughout southern and coastal B.C. seriously impacted community, irrigation, and hydroelectric water supplies in un-glaciated catchments (B.C. Ministry of Environment, 2010; Puska *et al.*, 2011). Our reconstruction suggests that droughts of the severity of those in 2003 and 2009 are not anomalous relative to the last several hundred years and should be accounted for in water management strategies (in fact, 2009 was not flagged as an extreme drought year based on the long-term threshold). Further, worst-case scenario natural droughts based on hydrometric data records are likely underestimated because more severe events occurred outside the hydrometric data period. It is possible that extreme natural low flows, paired with pressures from land-use and climate change, could result in a drought that is more severe than any since 1520. It is important to consider that very low flows in unglaciated Vancouver Island streams since 2009, especially in 2014 and 2015 (B.C. Ministry of Forests, Lands and Natural Resource Operations 2014; B.C. River Forecast Centre, 2015), may well have surpassed the severity of gauged droughts analysed for this study but could not be accounted for because of unavailable hydrometric data. The instrumental drought in 1992 may be more extreme than any in the reconstructed record, but this should be interpreted conservatively because the reconstructed streamflow variance is somewhat suppressed relative to the gauged record; actual magnitudes of pre-instrumental low flows may be as or more extreme than in 1992.

Our results suggest that relative to the preceding 440 years, the magnitudes of extreme droughts in Tsable River did not generally worsen from 1960 to 2009. Frequencies of lowest flow events also did not increase. A large outlier (high-flow year) in 1999 obscures a significant long-term negative trend in the gauged data (tested using a *t*-test of the slope of a regression of the instrumental flow data on time with 1999 removed) indicating that, with the exception of one year, Tsable River summer runoff has declined overall between 1960 and 2009. Analysis of SWE and precipitation data shows the outlier is related to very high snowfall (July–August precipitation was equal to the long-term 1960–2009 average in that year, while SWE was 217% of the average). This trend is not exceptional compared to the rest of the reconstruction, which suggests long-term streamflow declines of similar length and magnitude began around 1640, 1700, and 1800. Without data for the most extreme recent drought years, it is not possible to assess the unusualness of recent streamflow trends relative to the last few centuries.

Our findings highlight that consecutive years of very low flows have been extremely rare in the Tsable River system, which is consistent with minimal multi-year hydrological lag in small coastal watersheds and is an important hydrological feature for water management. Because the likelihood of extreme droughts is largely unrelated to conditions in the previous year, these events are highly unpredictable compared with large basins where persistent, multi-year drought is typical (Meko and Woodhouse, 2010). From a model-development standpoint, mimicking the zero-autocorrelation structure of the gauged summer streamflow data was critical for developing an accurate reconstruction. The dendrohydrological approach risked introducing ‘artificial’ persistence related to biological tree growth into our model, but use of residual chronologies guarded against this.

We found no evidence that the timing of below- or above- median streamflow in Tsable River corresponds with El Niño or weak- and non-El Niño years, in either the instrumental or reconstructed flow data. We evaluated El Niño years because they are typically associated with the low flows of interest to this study and which are most accurately estimated by our model. We did not evaluate associations with La Niña events that are typically more strongly associated with annual streamflow in hybrid watersheds, and correspond with enhanced winter precipitation and total runoff (Fleming *et al.*, 2007). In contrast, both the reconstructed and gauged streamflow records are influenced by winter PDO during the common data interval, with the strongest (negative) relationships occurring during the cool phase of the oscillation. This suggests an influence of SWE on summer low flows, consistent with cool PDO phases promoting more snow and higher snowmelt-derived runoff than warm phases (Fleming *et al.*, 2007). That the difference in correlations between the warm and cool phases was not statistically significant may have been because of small effective sample sizes (17 and 21 years). Intermittent ENSO-like power in the reconstructed record is evident in the approximately 2, 4, and 8-year bands of the wavelet power spectrum (Figure 7). PDO-like multidecadal power weakens between 1850 and 1910, as documented in other independent reconstructions of that oscillation (Gedalof and Smith, 2001b, MacDonald and Case, 2005).

Comparison with historical temperature, precipitation, and drought records is made difficult by a lack of relevant high-resolution records in Pacific Canada and the northwestern United States. The most pertinent records, which represent seasonal and/or spatial contexts distinct from those of this study, unsurprisingly yielded no notable similarities to historical Tsable River streamflow variability (Graumlich and Brubaker 1986; Larocque and Smith 2005; Luckman and Wilson 2005; Jarrett 2008; Wiles *et al.*, 2014). Neither does our reconstruction correspond with the few (non-hybrid) streamflow reconstructions developed in B.C. (Gedalof *et al.*, 2004, Hart *et al.*, 2010, Starheim *et al.*, 2013), similar records from Canada's western interior (Case and MacDonald 2003; Axelson *et al.*, 2009), or large-scale historical drought episodes such as the 1929–1940 Dust Dowl, the 1946–1956 drought in the southwestern United States (Fye *et al.*, 2003), or the 16th century megadrought (Stahle *et al.*, 2000). In the instrumental period, recent large-scale droughts in the Canadian Prairie provinces (e.g. 2002; 1999–2005; Canadian Foundation for Climate and Atmospheric Sciences 2010) are not expressed in the Tsable River gauged record, reinforcing the distinct hydroclimatological character of B.C.'s small coastal basins relative to surrounding regions.

CONCLUSION

Long-term perspectives on hydroclimate variability are critical for water management, with small temperate watersheds representing a frontier for paleohydrological modelling (Biondi and Strachan, 2012). We demonstrate that a dendrohydrological approach focused on the SWE-driven streamflow component is appropriate for determining drought-season runoff in small hybrid watersheds in coastal B.C. Tree-ring width records that are energy-limited by spring snowmelt timing were effective proxies for this streamflow component. Our reconstruction of Tsable River suggests that the severity of droughts in the 440 years preceding the instrumental record exceeded modern analogues such as the 2003 and 2009 droughts. The fact that recent 'extreme' events fall within a natural range of multi-century variability means that rather than being considered anomalies, extreme droughts should be expected and incorporated into drought management strategies. Most importantly, our findings suggest that worst-case scenario natural drought estimates based on hydrometric data are likely underestimated. Given projected climate trends and pressures from land-use change and increasing human demand for water in the study area, exacerbation of natural droughts can be reasonably anticipated in hybrid basins in coming decades, potentially resulting in low flows that exceed any since 1520.

There has been a significant decline in Tsable River summer runoff from 1960 to 2009 with the exception of one year. The frequency of extreme droughts did not increase between 1960 and 2009, but we could not account for severe events after 2009 — including the major droughts that occurred in 2014 and 2015 — because of a lack of hydrometric data. Both the gauged and reconstructed streamflow records experienced significantly greater runoff during cool phases of the PDO, which favour deep snowpacks. There was no measurable influence of El Niño on the timing of below-median flows but ENSO-type variability is apparent in the wavelet analysis. This variability may be related to the influence of La Niña on high flows in hybrid systems in the study area. While our reconstruction is primarily 'tuned' to SWE-related flow variability, a model that could account for the influence of spring/summer temperature on summer streamflow may improve drought magnitude estimates.

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REFERENCES

Axelson JN, Sauchyn DJ, Barichivich J. 2009. New reconstructions of streamflow variability in the South Saskatchewan River Basin from a network of tree ring chronologies, Alberta Canada. *Water Resources Research*. DOI:10.1029/2008WR007639.

B.C. Conservation Foundation. 2006. Vancouver Island Focus Watersheds: Trent and Tsable rivers. Retrieved from http://www.bccf.com/steelhead/focus5.htm

B.C. Ministry of Environment, Water Protection and Sustainability Branch. 2013. *A Water Sustainability Act for B.C.: legislative proposal overview*. Retrieved from http:// engage.gov.bc.ca/water sustainabilityact/files/2013/10/WSA_overview_web.pdf

B.C. Ministry of Environment. 2010. Preparing for Climate Change: British Columbia's Adaptation Strategy. Retrieved from http://www2.gov.bc.ca/gov/DownloadAsset?assetId=29CDF35B126E483A966B0D5DAE2E3E38&filename=adaptation_strategy.pdf

B.C. Ministry of Forests, Lands and Natural Resource Operations. 2014. Water Supply and Streamflow Conditions Bulletin. Retrieved from http://bcrfc.env.gov.bc. ca/bulletins/watersupply/index-watersupply.htm

B.C. River Forecast Centre. 2015. Snow Survey and Water Supply Bulletin. Retrieved June 20, 2015, from http://bcrfc.env.gov.bc.ca/bulletins/watersupply/current.htm

Beaulieu M, Schreier H, Jost G. 2012. A shifting hydrological regime: a field investigation of snowmelt runoff processes and their connection to summer base flow, Sunshine Coast, British Columbia. *Hydrological Processes* **26**(17): 2672–2682.

Biondi F, Strachan S. 2012. Dendrohydrology in 2050: challenges and opportunities. *Toward a Sustainable Water Future: Visions for* **2050**: 355–362.

Boninsegna A, Argolla J, Aravena J-C, Barichivich J, Christie D, Ferrera ME, Lara A, Le Quesne C, Luckman BH, Masiokas MH, Morales MS, Oliviera JM, Roig F, Srur A, Villalba R. 2009. Dendroclimatological reconstructions in South America: a review. *Palaeogeography, Palaeoclimatology, Palaeoecology* **281**(3–4): 210–228.

Bunn AG. 2008. A dendrochronology program library in R (dplR). *Dendrochronologia* **26**(2): 115–124.

Canadian Foundation for Climate and Atmospheric Sciences. 2010. Annual Progress Report for the Drought Research Initiative (DRI). Retrieved from http://www.drinetwork.ca/pdf/2009_DRI_Annual_Report.pdf.

Case RA, MacDonald GM. 2003. Tree ring reconstructions of streamflow for three Canadian prairie rivers. *JAWRA Journal of the American Water Resources Association* **39**(3): 703–716.

Cook ER, Holmes RL. 1986. *Users Manual for Program ARSTAN*. Laboratory of Tree-Ring Research, University of Arizona: Tucson, USA.

Cook E, Kairiūkštis L (Eds). 1990. *Methods of Dendrochronology: Applications in the Environmental Sciences*. Kluwer Aacademic Publishers: Netherlands.

Cook ER, Peters K. 1981. The smoothing spline: a new approach to standardizing forest interior tree-ring width series for dendroclimatic studies. *Tree-Ring Bulletin* **41**(1): 45–53.

Daly C, Gibson WP, Taylor GH, Johnson GL, Pasteris P. 2002. A knowledge-based approach to the statistical mapping of climate. *Climate Research* **22**(2): 99–113.

Dawdy D, Matalas N. 1964. Statistical and probability analysis of hydrologic data, part III: Analysis of variance, covariance and time series. In *Handbook of Applied Hydrology, A Compendium of Water-Resources Technology*, Chow VT (ed). McGraw-Hill: New York, NY; 8.68–8.90.

Dunn OJ. 1961. Multiple comparisons among means. *Journal of the American Statistical Association* **56**(293): 52–64.

Eaton B, Moore R. 2010. Regional hydrology. In *Compendium of Forest Hydrology and Geomorphology in British Columbia*, Pike RG, Redding TE, Moore RD, Winkler RD, Bladon KD (eds). Victoria, BC: Ministry of Forests and Range Research Branch / FORREX Forest Research Extension Partnership; 85–110.

Fleming SW, Whitfield PH, Moore RD, Quilty EJ. 2007. Regime-dependent streamflow sensitivities to Pacific climate modes cross the Georgia–Puget transboundary ecoregion. *Hydrological Processes* **21** (24): 3264–3287.

Fritts HC. 1976. *Tree Rings and Climate*. UK. Academic Press: London.

Fritts HC, Guiot J, Gordon GA. 1990. Verification. In *Methods of Dendrochronology: Applications in the Environmental Sciences*, Cook ER, Kairiūkštis L (eds). Kluwer Aacademic Publishers: Netherlands; 178–184.

Fye FK, Stahle DW, Cook ER. 2003. Paleoclimatic analogs to twentieth-century moisture regimes across the United States. *Bulletin of the American Meteorological Society* **84**(7): 901–909.

Gedalof Z, Smith DJ. 2001a. Dendroclimatic response of mountain hemlock (*Tsuga mertensiana*) in Pacific North America. *Canadian Journal of Forest Research* **31**(2): 322–332.

Gedalof Z, Smith DJ. 2001b. Interdecadal climate variability and regime-scale shifts in Pacific North America. *Geophysical Research Letters* **28** (8): 1515–1518.

Gedalof Z, Peterson D, Mantua N. 2004. Columbia river flow and drought since 1750. *JAWRA Journal of the American Water Resources Association* **40**(6): 1579–1592.

Graumlich L, Brubaker L. 1986. Reconstruction of annual temperature (1590–1979) for Longmire, Washington, derived from tree rings. *Quaternary Research* **25**(2): 223–234.

Grissino-Mayer HD. 2001. Research report evaluating crossdating accuracy: a manual and tutorial for the computer program COFECHA. *Tree-Ring Research* **57**(1): 115–124.

Hansen-Bristow K. 1986. Influence of increasing elevation on growth characteristics at timberline. *Canadian Journal of Botany* **64**(11): 2517–2523.

Hart SJ, Smith DJ, Clague JJ. 2010. A multi-species dendroclimatic reconstruction of Chilko River streamflow, British Columbia, Canada. *Hydrological Processes* **24**(19): 2752–2761.

Holmes RL. 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* **43**(1): 69–78.

Jarrett P. 2008. *A Dendroclimatic Investigation of Moisture Variability and Drought in the Greater Victoria Water Supply Area, Vancouver Island, British Columbia*. Unpublished MSc. thesis, University of Victoria: Victoria B.C., Canada.

Kiffney P, Bull J, Feller M. 2002. Climatic and hydrologic variability in a coastal watershed of southwestern British Columbia. *JAWRA Journal of the American Water Resources Association* **38**(5): 1437–1451.

Klinka K, Pojar J, Meidinger D. 1991. Revision of biogeoclimatic units of coastal British Columbia. *Northwest Science* **65**(1): 32–47.

Larocque SJ, Smith DJ. 2005. A dendroclimatological reconstruction of climate since AD 1700 in the Mt. Waddington area, British Columbia Coast Mountains. *Canada. Dendrochronologia* **22**(2): 93–106.

Laroque CP. 2002. *Dendroclimatic Response of High-Elevation Conifers, Vancouver Island, British Columbia (Doctoral Dissertation)*. University of Victoria: Victoria, BC.

Laroque CP, Smith DJ. 1999. Tree-ring analysis of yellow cedar (*Chamaecyparis nootkatensis*) on Vancouver Island British Columbia. *Canadian Journal of Forest Research* **29**(1): 115–123.

Lill A. 2002. Greater Georgia Basin steelhead recovery action plan. Report prepared for BC Conservation Foundation: Greater Georgia Basin Steelhead Recovery Plan, Nanaimo, BC. Retrieved from http://www.bccf.com/steelhead /pdf/Steelheadreport092702.pdf

Loaiciga H, Haston A, Michaelsen J. 1993. Dendrohydrology and long-term hydrologic phenomena. *Reviews of Geophysics* **31**(2): 151–171.

Luckman BH, Wilson RJS. 2005. Summer temperatures in the Canadian Rockies during the last millennium: a revised record. *Climate Dynamics* **24**(2–3): 131–144.

MacDonald GM, Case RA. 2005. Variations in the Pacific Decadal Oscillation over the past millennium. *Geophysical Research Letters* **L08**: 703. DOI:10.1029/2005GL022478.

Mantua N. 2002. Pacific-Decadal Oscillation. In MacCracken M, Perry JS. *Encyclopedia of Global Environmental Change*. **1**: 592–594 (Eds). John Wiley and Sons: Chichester: UK.

Mantua N, Tohver I, Hamlet A. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climatic Change* **102**(1–2): 187–223.

Marcinkowski K, Peterson DL, Ettl GJ. In press. Nonstationary Temporal Response of Mountain Hemlock Growth to Climatic Variability in the North Cascade Range. *Canadian Journal of Forest Research*. In press. DOI: 10.1139/cjfr-2014-0231

Margolis E, Meko D, Touchan R. 2011. A tree-ring reconstruction of streamflow in the Santa Fe River, New Mexico. *Journal of Hydrology* **397**(1): 118–127.

Mays LM. 2005. *Water Resources Engineering*. Wiley & Sons: New York, NY.

Meko DM. 2006. Tree-ring inferences on water-level fluctuations of Lake Athabasca. *Canadian Water Resources Journal* **31**(4): 229–248.

Meko D, Woodhouse C. 2010. Application of streamflow reconstruction to water resources management. In *Dendroclimatology*, Hughes MK, Swetnam TW, Diaz HF (eds). Springer: Netherlands; 231–261.

Meko D, Touchan R, Anchukaitis K. 2011. Seascorr: a MATLAB program for identifying the seasonal climate signal in an annual tree-ring time series. *Computers & Geosciences* **37**(9): 1234–1241.

Michaelsen J. 1987. Cross validation in statistical climate forecast models. *Journal of Applied Meteorology* **26**(11): 1589–1600.

Moore RD, Allen DM, Stahl K. 2007. Climate change and low flows: influences of groundwater and glaciers. Final report prepared for Climate Change Action Fund, Natural Resources Canada, Vancouver, BC. Retrieved from https://www.sfu.ca/personal/ dallen/ CCAF_ A875-FinalReport.pdf

Mosteller F, Tukey J. 1977. *Data Analysis and Regression: a Second Course in Statistics*. Addison-Wesley Publishing Company: Reading, MA.

Newcombe RG. 1998. Interval estimation for the difference between independent proportions: comparison of eleven methods. *Statistics in Medicine* **17**(8): 873–890.

Pederson N, Jacoby GC, D'Arrigo RD, Cook ER, Buckley BM, Dugarjav C, Mijiddorj R. 2001. Hydrometeorological reconstructions for Northeastern Mongolia derived from tree rings: 1651–1995. *Journal of Climate* **14**(5): 872–881.

Peterson DW, Peterson DL. 1994. Effects of climate on radial growth of subalpine conifers in the North Cascade Mountains. *Canadian Journal of Forest Research* **24**(9): 1921–1932.

Peterson DW, Peterson DL. 2001. Mountain hemlock growth responds to climatic variability at annual and decadal time scales. *Ecology* **82**(12): 3330–3345.

Pike R, Bennett K, Redding T, Werner AT, Spittlehouse DL, Moore RD, Murdock TQ, Beckers J, Smerdon BD, Bladon KD, Foord VN, Campbell DA, Tschaplinski PJ. 2010. Climate change effects on watershed processes in British Columbia. In *Compendium of Forest Hydrology and Geomorphology in British Columbia*, Pike RG, Redding TE, Moore RD, Winkler RD, Bladon KD (eds). Ministry of Forests and Range Research Branch / FORREX Forest Research Extension Partnership: Victoria, BC; 699–747.

Puska L, Clements L, Chandler K. 2011. Climate change and food security on Vancouver Island: discussion paper. Report prepared by Vancouver Island Local Food Project, Victoria, BC. Retrieved from http://www.uvic.ca/research/centres/cue/assets/docs /Climate%20Change% 20and%20Food%20Report.pdf

Rodenhuis DR, Bennett KE, Werner AT, Murdock TQ, Bronaugh, D. 2007. Climate overview 2007: Hydro-climatology and future climate impacts in British Columbia. Report prepared by the Pacific Climate Impacts Consortium, Victoria, BC. Retrieved from http://www.pacificclimate.org/sites/default/files/publications/Rodenhuis.ClimateOverview.Mar2009.pdf.

Sauchyn DJ, Vanstone J, St. Jacques J-M, Sauchyn R. 2014. Dendrohydrology in Canada's western interior and applications to water resource management. *Journal of Hydrology*. DOI:10.1016/j.jhydrol.2014.11.049.

Silvestri S. 2004. Stock Assessment of winter steelhead trout in Goldstream, Sooke, Trent and Tsable Rivers, 2004. Report prepared by BC Conservation Foundation: Greater Georgia Basin Steelhead Recovery Plan, Nanaimo, BC. Retrieved from http://a100.gov.bc.ca/apps data/ acat/documents/r5850/StockAssessmentReportFinal-NonPrintingCopy_1143403749 784_bb9844 0f95634e108ba9ff1269fd7f72.pdf

Smith DJ, Laroque CP. 1998. High-elevation dendroclimatic records from Vancouver Island. In *Proceedings of the Workshop on Decoding Canada's Environmental Past: Climate Variations and Biodiversity Change during the Last Millennium*, MacIver D, Meyer RE (eds). Atmospheric Service, Environment Canada: Downsview, Ont; 33–44.

Snedecor GW, Cochran WG. 1989. *Statistical Methods*. 1A. Iowa State University Press: Ames.

Stahl K, Moore RD, Mckendry IG. 2006. The role of synoptic-scale circulation in the linkage between large-scale ocean–atmosphere indices and winter surface climate in British Columbia, Canada. *International Journal of Climatology* **26**(4): 541–560.

Stahle DW, Cook ER, Cleaveland MK, Therrell MD, Meko DM, Grissino-Mayer HD, Watson E, Luckman BH. 2000. Tree-ring data document 16th century megadrought over North America. *Eos, Transactions American Geophysical Union* **81**(12): 121–125.

Starheim CCA, Smith DJ, Prowse TD. 2013. Dendrohydroclimate reconstructions of July–August runoff for two nival-regime rivers in west central British Columbia. *Hydrological Processes* **27**(3): 405–420.

Stephens K, Ven der Gulik T, Heath T. 1992. Water, water everywhere: does British Columbia really need a water conservation strategy? *The BC Professional Engineer* **43**(8): 3–7.

Torrence C, Compo G. 1998. A practical guide to wavelet analysis. *Bulletin of the American Meteorological Society* **79**(1): 61–78.

Van Loon and Laaha AF, Laaha G. 2015. Hydrological drought severity explained by climate and catchment characteristics. *Journal of Hydrology* **256**(1): 3–14.

Wang T, Hamann A, Spittlehouse D, Aitken SN. 2006. Development of scale-free climate data for western Canada for use in resource management. *International Journal of Climatology* **26**(3): 383–397.

Wang T, Hamann A, Spittlehouse D, Murdock TN. 2012. ClimateWNA—high-resolution spatial climate data for western North America. *Journal of Applied Meteorology and Climatology* **51**(1): 16–29.

Watson E, Luckman BH. 2005. Spatial patterns of preinstrumental moisture variability. *Journal of Climate* **18**(15): 2847–2863.

Wigley TML, Briffa KR, Jones PD. 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Applied Meteorology* **23**(2): 201–213.

Wiles GC, D'Arrigo R, Barclay D, Wilson RS, Jarvis SK, Vargo L, Frank D. 2014. Surface air temperature variability reconstructed with tree rings for the Gulf of Alaska over the past 1200 years. *The Holocene* **24**(2): 198–208.

WinDENDRO. 1996. *WinDENDRO reference manual V. 6.1b, February 1996*. Re´gent Instruments, Que´bec.

Woodhouse CA, Gray ST, Meko DM. 2006. Updated streamflow reconstructions for the Upper Colorado River basin. *Water Resources Research* DOI:10.1029/2005WR004455.

Worrall J. 1983. Temperature–bud-burst relationships in amabilis and subalpine fir provenance tests replicated at different elevations. *Silvae Genetica* **32**(5/6): 203–209.

Yang YK, Huang Q, Liu Y, Wang WK, Wang YM. 2010. Advances in streamflow reconstruction using tree-ring data. *Advances in Water Science* **21**(3): 430–434.

Zhang Q, Hebda R. 2004. Variation in radial growth patterns of *Pseudotsuga menziesii* on the central coast of British Columbia, Canada. *Canadian Journal of Forest Research* **34**(9): 1946–1954.

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LONG-TERM CHANGES IN STREAMFLOW FOLLOWING LOGGING IN WESTERN OREGON AND ASSOCIATED FISHERIES IMPLICATIONS[1]

Brendan J. Hicks, Robert L. Beschta, and R. Dennis Harr[2]

ABSTRACT: The long-term effect of logging on low summer streamflow was investigated with a data set of 36 years. Hydrologic records were analyzed for the period 1953 and 1988 from Watershed (WS) 1 (clearcut logged and burned), WS 2 (unlogged control), and WS 3 (25 percent patch-cut logged and burned) in the H. J. Andrews Experimental Forest, western Cascade Range, Oregon. These records spanned 9-10 years before logging, and 21-25 years after logging and burning. Streamflows in August were the lowest of any month, and were unaffected by occasional heavy rain that occurred at the beginning of summer. August streamflows increased in WS 1 compared to WS 2 by 159 percent following logging in WS 1, but this increase lasted for only eight years following the start of logging in 1962. Water yield in August for 1970-1988 observed from WS 1 was 25 percent less than predicted from the control (WS 2, ANOVA, p=0.032).

Water yield in August increased by 59 percent after 25 percent of the area of WS 3 was patch-cut logged and burned in 1963. In contrast to WS 1, however, water yields from WS 3 in August were consistently greater than predicted for 16 years following the start of logging, through to 1978. For the 10 years, 1979-1988, water yield observed in August from WS 3 was not different than predicted from the control (WS 2, ANOVA, p-0.175).

The contrasting responses of WS 1 and 3 to logging are thought to be the result of differences in riparian vegetation caused by different geomorphic conditions. A relatively wide valley floor in WS 1 allowed the development of hardwoods in the riparian zone following logging, but the narrow valley of WS 3 and limited sediment deposits prevented establishment of riparian hardwoods.

Low streamflows during summer have implications for salmonid survival. Reduced streamflow reduces the amount of rearing habitat, thus increasing competition. Combined with high water temperatures, reduced streamflow can lead directly to salmonid mortality by driving salmonids from riffles and glides, and trapping them in drying pools. Low streamflow also increases oxygen depletion caused by leaves from riparian red alders.

(KEY TERMS: streamflow; logging; salmonids; water use; water storage; evapotranspiration; dissolved oxygen.)

INTRODUCTION

Many studies have shown that removal of vegetation by clearcut logging results in increased annual water yield (e.g., Bosch and Hewlett, 1982; Harr, 1983). This increased streamflow is caused by reduction of the water loss associated with vegetation through interception, evaporation, and transpiration. It is generally assumed that some time after clearcut logging, annual water yields will approach prelogging values as vegetation regrows (Kovner, 1956; Rothacher, 1970). The rate of regrowth and concomitant reduction of water yield depends on a number of factors, among which are climate, plant species, soil, and altitude. Studies at the H. J. Andrews Experimental Forest in the Cascade Range of western Oregon (Figure 1) predicted that return of annual water yield to prelogging levels might take about 27 years in this environment (Equation 1, in Harr, 1983).

Whether water yield actually returns to the prelogging level, or to some level above or below it, has not previously be established in the Pacific Northwest of the U.S. Few studies have sufficiently long periods of observation with which to investigate long-term water yield following clearcut logging. In addition, short-duration studies have covered only the period of increased water yield immediately following logging (e.g., the Alsea Watershed Study, Harris, 1977), being terminated before regrowth of vegetation subsequently reduced logging-related flow increases to pretreatment levels. This study examines the long-term effect of timber harvest, taking into account the period of vegetative regrowth following logging.

In certain environments, water yields might decrease following logging. Instead of the expected increase, a small (<20 mm) decrease in annual water

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yield was observed after 25 percent of a watershed was patch-cut logged at Fox Creek, Bull Run Municipal Watershed, on the western slopes of Mt. Hood, Cascade Range, western Oregon (Harr, 1982). The experimental watersheds at Fox Creek extend in elevation from 840 to 1070 m, where fog is common. Interception of wind-blown fog by 46-55 m-tall conifers is an important source of moisture in the Fox Creek watersheds, and fog interception was reduced by removal of vegetation, thereby reducing the annual amount of moisture available at the soil surface (i.e., precipitation plus fog drip) by up to 30 percent compared to prelogging levels. Fog has also been shown to contribute significantly to annual precipitation in coastal forests in Oregon and northern California (Isaac, 1946; Azevedo and Morgan, 1974).

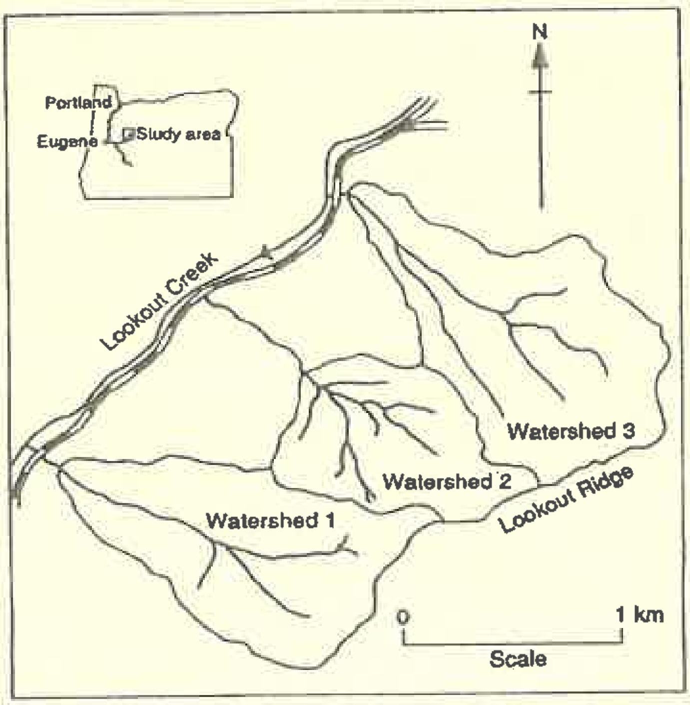

Figure 1. Location of Watersheds 1 and 2 in the H. J. Andrews Experimental Forest, Cascade Range, Oregon (after Rothacher *et al.*, 1967).

Forests have a substantial effect on water yield in environments other than fog zones. Interception of precipitation and transpiration by trees have a pronounced effect on water balance in regions with moderate to high annual precipitation (above about 1500 mm) and dry summers (Pearce and Rowe, 1979). Many of the production forests in western North America occupy such environments, and freshwater resources could be affected as second-growth fore replaces mature forest.

Diminishing water flows from June to Septembe can adversely affect stream inhabitants. Even sma reductions in water yield in summer can be detrimer tal to salmonids. Several studies have suggested th volume of summer rearing habitat is a significant fa tor affecting fish production (Smoker, 1953; Evere and Sedell, 1984; Elliott, 1985; Hicks, 1990). Als when flow is reduced, stream temperatures ma increase, causing increased stress, disease, and con petition among fish. Temperatures preferred by rai bow trout (*Oncorhynchus mykiss*, formerly *Salm gairdneri*), or optimum for their growth, range fro 12 to 22°C. Temperatures of 25°C or above may b lethal (Cherry *et al.*, 1975). Increased yield of coar sediment following logging can increase the effect low flows, causing shallowing and widening of strea channels (Lyons and Beschta, 1983; Tripp and Pouli 1986).

METHODS

Predicting the response of summertime strean flows to forest management activities requires a lo period of record, preferably from paired watershed One of the few long-term records of changes in wat yield from paired watersheds in an environment wi moderate to high annual precipitation and dry sun mers comes from Watersheds (WS) 1, 2, and 3 of t H. J. Andrews Experimental Forest (Figure 1). T study basins have areas of 96 ha, 60 ha, and 101 h respectively, and are underlain by volcanic rock including andesite and basalt lava flows, and tu breccias (Rothacher *et al.*, 1967). The watershe range from 442 to 1082 m, at which elevation the va majority of precipitation falls as rain (Rothacher *e al.*, 1967). Snow that does fall between 400 and 11 m elevation in western Oregon is transient, usual melting in 3-4 days during subsequent rain (Ha 1983), and thus is of little significance to summ streamflows.

Streamflows were calibrated by taking baseli measurements in the unlogged watersheds from 19 to 1961 for WS 1, and from 1953 to 1962 for WS Logging began in WS 1 in 1962, and continued un 1966. Remaining vegetation and logging slash in W 1 was burned in October 1966 (Rothacher, 1970). late 1962 and early 1963, 25 percent of the area of W 3 was patch-cut logged, and these cleared patch were burned in September 1963. Watershed remained unlogged as a control, with precipitati measured at a climate station in WS 2. Months we grouped by water year (October 1 to September 30) for analysis of streamflow and precipitation.

Water yields for WS 1, 2, and 3, analyzed by Harr (1983), were derived from data transcribed from continuous records using methods that visually estimated instantaneous flow from the water level traces (pers. comm., Don Henshaw, Pacific Northwest Research Station, Corvallis, Oregon). We have reanalyzed results from data digitally transcribed from the original records for part of the prelogging period (1953-1959), and we have added seven more years of data to the analysis of Harr (1983).

Data from the prelogging calibration period were used to relate annual and summer water yields in millimeters from WS 1 and 3 following timber harvest to water yield from the control watershed (WS 2). Calibration periods were nine years for WS 1 (1953-1961) and 10 years for WS 3 (1953-1962). Least-squares regression was used to derive the prelogging relationship between streamflows in WS 1 and 2, and between streamflows in WS 3 and 2. The linear model Y=a+bX was used, where Y=observed water yield from WS 1 or 3 (treated watersheds) and X=observed water yield from WS 2 (unlogged control). Observed water yield from WS 2 was then used to predict water yield expected from WS 1 and 3 before and after logging on the basis of the recalculated regression relationships in Table 1.

RESULTS

Water Yield After Logging

Slope and intercept for regression relationships between WS 1 and 2 from this analysis were very close to those calculated using the same methods by Harr (1983) for July to September (Table 1). The recalculated regressions of prelogging water yields for WS 1 on WS 2 were significant for all months and combinations of months (Table 1). Regression relations for prelogging water yields for WS 3 on WS 2 were also significant for all months and combinations of months, except for July. The regressions of total annual prelogging water yield for both WS 1 and WS 3 on WS 2 were also significant ($p<0.001$, Table 1).

The period of increased summer flow observed following the start of logging in WS 1 compared to the unlogged WS 2 was short-lived (about eight years,

TABLE 1. Results of Least-Squares Linear Regression Analysis of Summer and Annual Water Yields Before Logging for Watershed 1 (1953-1961) and Watershed 3 (1953-1962, depending variables, Y) on Watershed 2 (independent variable, X) in the H. J. Andrews Experimental Forest, Western Oregon Cascades (n=9 for WS 1, n=10 for WS 3). Results from Harr (1983) compared to those from this paper for digitized data. The model used is Y=a+bX.

Time Period	Slope (b)	Intercept (a)	r^2	Significance of Regression Model (p)
WATERSHED 1 – Clearcut Logged (this paper)				
July	0.461	2.06	0.62	0.012
August	0.544	0.14	0.67	0.007
September	1.001	–2.60	0.89	<0.001
July to August	0.513	1.70	0.72	0.004
July to September	0.704	–2.84	0.80	0.001
Annual	0.944	–97.92	0.96	<0.001
HARR (1983)				
July to September	0.731	–2.74	0.72	0.004
WATERSHED 3 – 25 Percent Patch-Cut Logged (this paper)				
July	0.629	8.61	0.20	0.198
August	1.018	0.89	0.74	0.001
September	1.275	–0.14	0.92	<0.001
July to August	0.823	8.59	0.43	0.040
July to September	0.861	11.43	0.63	0.006
Annual	0.839	110.63	0.94	<0.001

Figure 2A). After 1970, observed water yield from WS 1 for August was generally less than that predicted from the model; reduced water yield has occurred for 18 of 19 years (1970-1988). In contrast to WS 1, however, water yields from WS 3 in August were consistently above predicted through 1978, 16 years after the start of logging (Figure 2B).

Differences between observed and predicted water yields for WS 1 were compared for three distinct periods of record (Table 2). The three periods wer (1) 1953-1961 (prelogging calibration), (2) 1962-196 (the period of increased water yield that included log ging and burning, and (3) 1970-1988 (the following 1 years of low water yield). Means were compared wit single-classification ANOVA. Differences betwee observed and predicted water yields for WS increased dramatically following clearcut logging fo 1962-1969. The increase in water yield for Augus

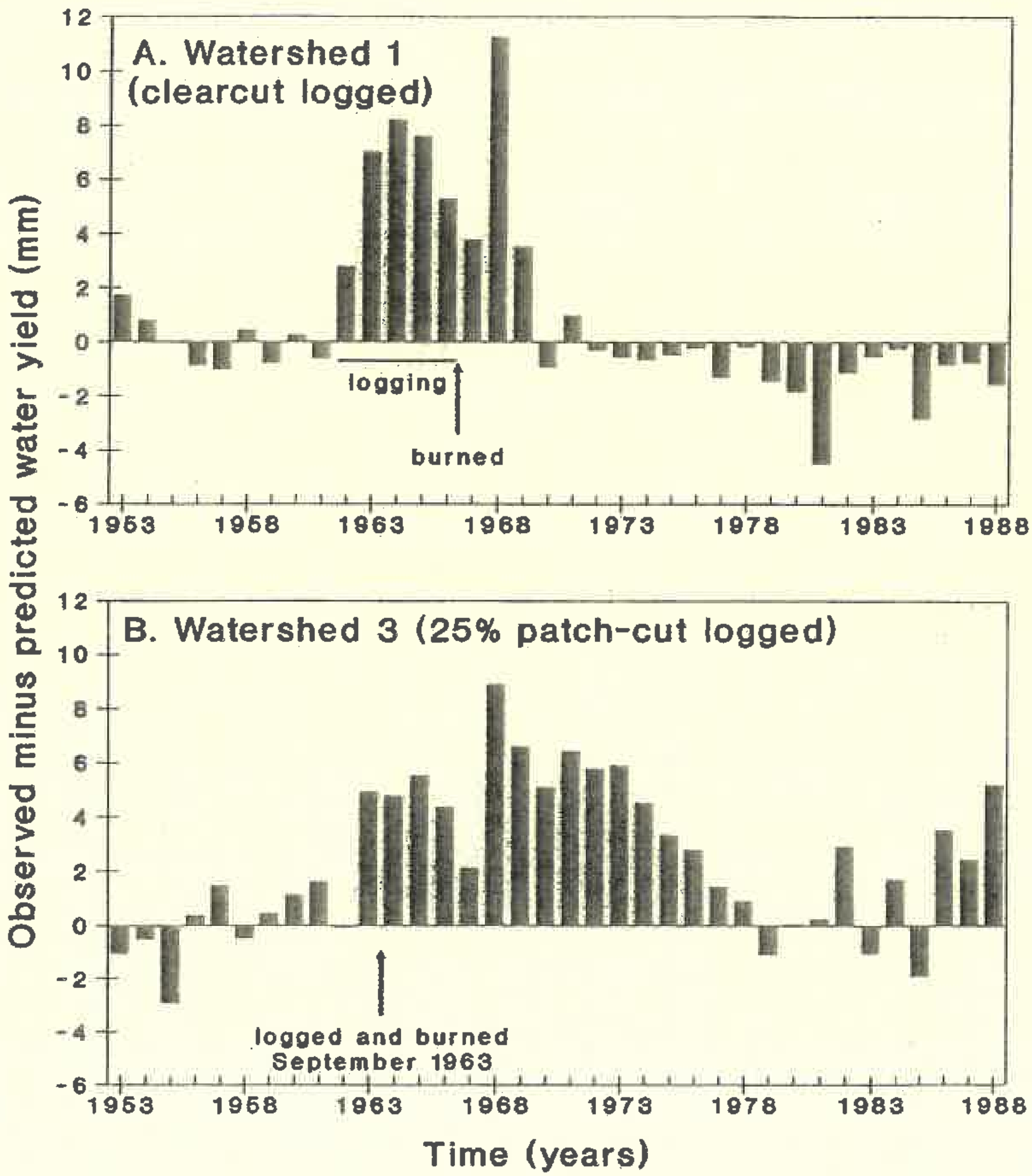

Figure 2. Differences Between Observed and Predicted Water Yield for August from Watershed 1 (A) and Watershed 3 (B) in H. J. Andrews Experimental Forest, Western Oregon Cascades, Before and After Logging (1953-1988).

TABLE 2. Means of Observed and Predicted Water Yields from Watersheds 1, 2, and 3 Before and After Logging (1953-1988) in the H. J. Andrews Experimental Forest, Western Oregon Cascades, for (A) Period of Prelogging Streamflow Calibration, (B) Period of Increased Water Yield During and Immediately Following Logging, and (C) Period of Reduced Water Yield Following Vegetative Regrowth. All water yields increased significantly in the period immediately following logging compared to the prelogging period.

Months	Years of Record	n	Mean Observed Water Yield (mm)	Mean Observed Water Yield (1/s/km²)	Predicted Water Yield (mm)	Mean Observed Minus Predicted Water Yield (mm)	(percent)	mean	se*	Significance of Difference Between Periods A and C** (α)
WATERSHED 1 – Clearcut Logged										
July	(A) 1953-1961	9	9.1	3.40	9.1	0.0	0	0.00	0.11	
	(B) 1962-1969	8	14.7	5.50	6.7	8.1	121	3.01	0.51	0.200
	(C) 1970-1988	19	7.0	2.63	7.9	–0.8	–10	–0.30	0.15	
August	(A) 1953-1961	9	5.7	2.12	5.7	0.0	0	0.00	0.11	
	(B) 1962-1969	8	10.1	3.78	3.9	6.2	159	2.30	0.38	0.032
	(C) 1970-1988	19	3.0	1.11	4.0	–1.0	–25	–0.37	0.10	
September	(A) 1953-1961	9	7.2	2.79	7.2	0.0	0	0.00	0.21	
	(B) 1962-1969	8	11.8	4.57	4.2	7.7	183	2.95	0.72	0.256
	(C) 1970-1988	19	7.4	2.87	6.3	1.2	19	0.45	0.25	
July to August	(A) 1953-1961	9	14.8	2.76	14.8	0.0	0	0.00	0.08	
	(B) 1962-1969	8	24.9	4.64	10.4	14.4	138	2.74	0.82	0.039
	(C) 1970-1988	19	10.0	1.87	11.8	–1.7	–14	–0.33	0.10	
July to September	(A) 1953-1961	9	22.0	2.77	22.0	0.0	0	0.00	0.09	
	(B) 1962-1969	8	36.7	4.62	13.9	22.8	164	2.90	0.39	0.885
	(C) 1970-1988	19	17.5	2.20	17.2	0.3	2	0.03	0.15	
Annual	(A) 1953-1961	9	1377.9	43.69	1377.4	0.4	0	0.01	0.55	
	(B) 1962-1969	8	1439.3	45.64	1073.2	366.1	31	11.61	1.83	<0.001
	(C) 1970-1988	19	1426.8	45.24	1140.1	286.7	25	9.09	0.42	
WATERSHED 2 – Unlogged Control										
July	1953-1988	36	12.7	4.74						
August	1953-1988	36	7.8	2.92						
September	1953-1988	36	8.6	3.33						
July to August	1953-1988	36	20.5	3.83						
July to September	1953-1988	36	29.1	3.67						
Annual	1953-1988	36	1358.6	43.08						
WATERSHED 3 – 25 Percent Patch-Cut Logged										
August	(A) 1953-1962	10	11.2	4.19	11.2	0.0	0	0.00	0.16	
	(B) 1963-1978	16	12.4	4.63	7.8	4.6	59	1.70	0.19	0.175
	(C) 1979-1988	10	9.3	3.47	8.1	1.2	15	0.44	0.27	
September	(A) 1953-1962	10	11.9	4.60	11.9	0.0	0	0.00	0.20	
	(B) 1963-1978	16	14.1	5.43	10.1	4.0	40	1.54	0.25	0.159
	(C) 1979-1988	10	12.4	4.79	11.1	1.3	12	0.51	0.28	
July to August	(A) 1953-1962	10	29.2	5.44	29.1	0.0	0	0.00	0.24	
	(B) 1963-1978	16	28.5	5.32	22.8	5.7	25	1.06	0.21	0.976
	(C) 1979-1988	10	25.9	4.84	26.0	0.0	0	–0.01	0.27	
July to September	(A) 1953-1962	10	41.1	5.17	41.1	0.0	0	0.00	0.17	
	(B) 1963-1978	16	42.6	5.36	33.2	9.4	28	1.19	0.22	0.634
	(C) 1979-1988	10	38.4	4.83	37.2	1.1	3	0.14	0.24	
Annual	(A) 1953-1962	10	1403.7	44.51	1403.4	–0.3	0	0.01	0.59	
	(B) 1963-1978	16	1330.4	42.19	1221.3	109.0	9	3.46	0.48	0.160
	(C) 1979-1988	10	1177.6	37.34	1144.3	33.3	3	1.06	0.40	

*Standard error.
**Means for prelogging calibration period (A) and period of reduced water yield (C) compared with single classification ANOVA.

alone was 159 percent, which corresponds to an increase in specific discharge of 2.3 $l/s/km^2$ (Table 2).

Within three years of the completion of logging and burning on WS 1, regrowth of vegetation had eliminated the increases in summer water yield. Water yields for August over the period 1970-1988 were 25 percent (i.e., 1.0 mm) lower in WS 1 than predicted from WS 2 compared to the prelogging period (1953-1961, p=0.032). Water yields for July and August combined were 14 percent (i.e., 1.7 mm) lower for 1970-1988 than for 1953-1961 (p=0.039, Table 2). Specific discharge for August was 0.37 $l/s/km^2$ lower than predicted for 1970-1988. The differences in observed minus predicted water yields between the 1953-1961 and 1970-1988 periods for July or September alone, or for July to September combined, were not significant (p>0.200).

Water yield in September was extremely variable among years. Rains at the end of summer sometimes began part way through September, and sometimes occurred after the end of September. For the period 1953-1988 the coefficient of variation of streamflow from the control watershed, WS 2, was 62 percent for September, but only 41 percent for August. Variability in streamflow masked the response to logging of September water yield.

There were three distinct periods in the summertime hydrologic record for WS 3 (Figure 2B). These periods were (1) 1953-1962 (prelogging calibration), (2) 1963-1978 (the period of increased water yield following logging and burning), and (3) 1979-1988 (the following 10 years during which water yield appeared to have returned to pretreatment levels). Observed water yield increased compared to predicted by 59 percent for August alone, and by 25 percent for July and August combined, immediately following the start of logging (1963-1978, Table 2). Water yields for 1979-1988 were not significantly different from the 1953-1962 period of prelogging calibration for combinations of July-September yields, or for annual totals (Table 2).

Comparing Figures 2 and 3, it is obvious that the response of annual water yield to logging is not necessarily a good predictor of changes in summer water yield. Differences between patterns of water yield for August and annual water yield are a result of, at least in part, seasonal patterns of precipitation and streamflow for forested watersheds in western Oregon and Washington. About 80 percent of total annual precipitation occurs between October 1 and March 31, leading to low streamflows in late summer. The excess of potential evapotranspiration over precipitation results in a water deficit in the H. J. Andrews Experimental Forest from June to September (Rothacher, 1971). Thus only 2-4 percent of average annual streamflow occurs during July, August, and September (Harr, 1983). For example, streamflow fo July 1 to September 30 from WS 2 was 2.4 ± 0.5 per cent (mean ± 95 percent confidence intervals, n=36) o annual totals between 1953 and 1988.

We examined predictions that the increase in annual water yield caused by logging would return t zero by 1992, 27 years after 1965 (Harr, 1983). Analyzing data for 1953-1981, Harr (1983) derive the model Y=513.2–19.1X for reducing water yield where Y=observed increase in annual water yield (in inches) compared to control, and X=time since loggin (r^2=0.75, n=16). Adding seven years of record (i.e. 1982-1988 inclusive), we found that the steep declin in annual water yield for WS 1 from 1966 to 1976 flat tened out from 1977 to 1988, so that there has beer little further reduction in annual water yield (Fig ure 3A). Water yield from WS 1 for 1970-1988 wa still 25 percent greater than for 1953-1961, the prel ogging period (p<0.001, Table 2). The model calculat ed from least squares regression for data fo 1965-1988 (the period used by Harr, 1983) wa Y=435.9–9.72X (r^2=0.53, p<0.001, n=24), indicate that annual water yields (in millimeters) will retur to prelogging values 46 years after logging, in 2011. Annual water yield from WS 3 from 1979 to 1988 wa not significantly different from prelogging level (p=0.160, Table 2, Figure 3B).

Changes in Vegetation

Before logging, the vegetation of the hillslopes o WS 1 was dominated by old-growth (300-500 year old and mature (125 year old) Douglas-fir (*Pseudotsuga menziesii* (Mirb). Franco), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) of varying age (Dyrness, 1973). Riparian vegetation consisted largely of old-growth conifers and shade-adapted herbaceous species. Tall conifers suppressed establishment and growth of deciduous vegetation along the channel.

After logging and burning, vegetation graduall reestablished in WS 1 and 3. The recovery has been described elsewhere (Halpern, 1988, 1989), and followed the pattern typical for the Pacific Northwest with forbs, sprouting hardwoods, and miscellaneous pioneer species initially establishing on the hillslopes. Douglas-fir trees now occupy most slopes. Red alde (*Alnus ruba* Bong.) dominates the riparian zone of WS 1 (pers. comm., F. J. Swanson, Pacific Northwest Research Station, Corvallis, Oregon), and willow (*Salix* spp.), and cottonwood (*Populus trichocarpa* Torr. and Gray) are also established in and adjacent to the stream.

Different geomorphic conditions in the valley floor of WS 1, 2, and 3 have determined the development o riparian vegetation. Watershed 1, with a relativel

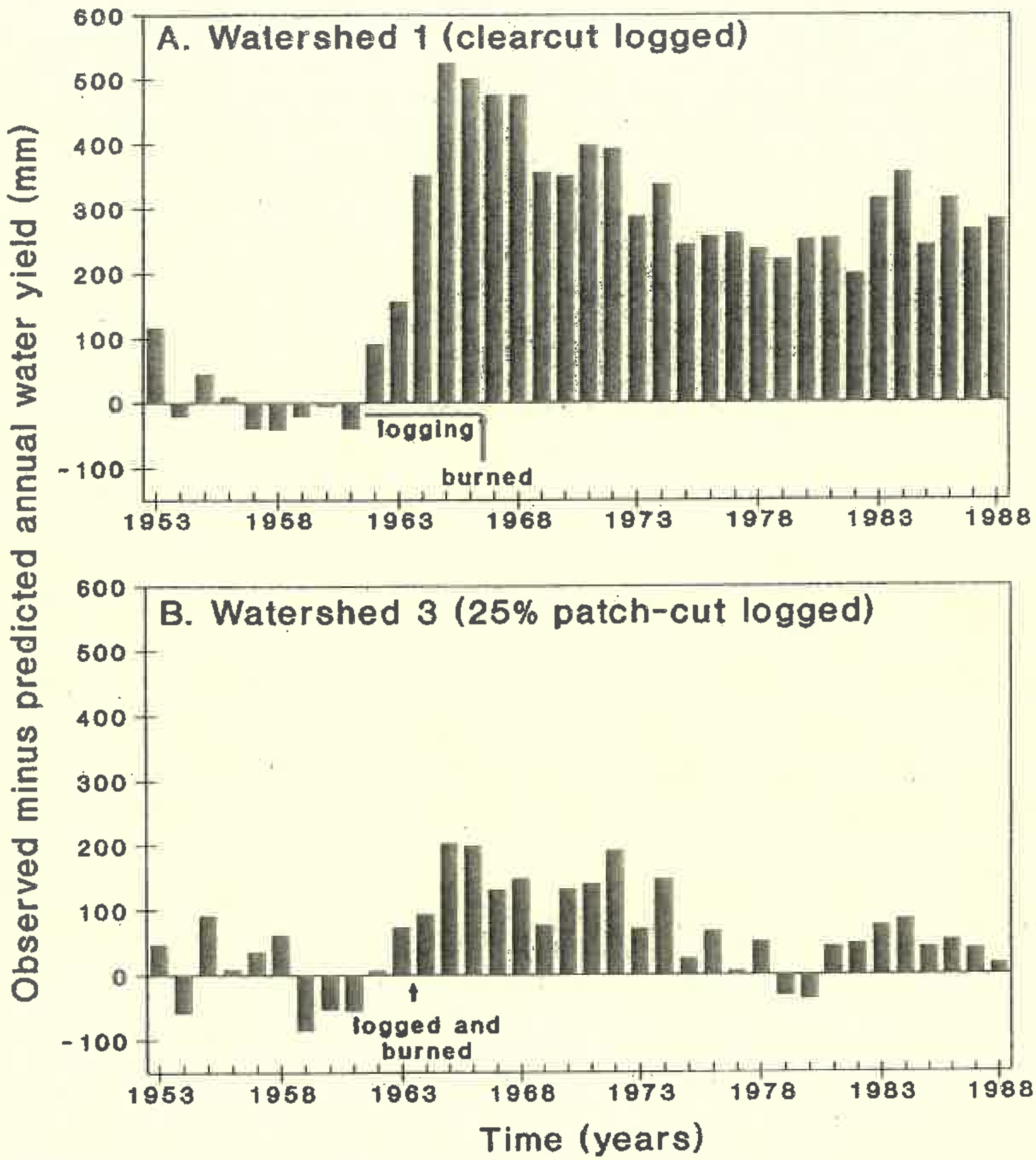

Figure 3. Differences Between Observed and Predicted Water Yield for Watershed 1 (A) and Watershed 3 (B), H. J. Andrews Experimental Forest, Western Oregon Cascades, Before and After Logging (1953-1988).

wide valley floor compared to WS 2 and 3, has well-developed riparian hardwoods. As a consequence of the narrow valley floor in WS 3, there has been little opportunity for hardwoods to establish in the riparian zone following logging. In addition, sediment deposits on which riparian hardwoods might have established have been removed from much of the valley of WS 3 by debris torrents caused by floods in December 1961, December 1964, and January 1965 (Fredriksen, 1963, 1965). Hardwoods are limited in the riparian zone of WS 2 because (1) the small amount of sediment at the channel edge prevents rooting, and (2) conifers rooted on side slopes suppress hardwood establishment along the channel (pers. comm., F. J. Swanson, Pacific Northwest Research Station, Corvallis, Oregon).

DISCUSSION

Significance of Long-Term Trends in Water Yield

Increased annual water yield has been one of the benefits generally attributed to timber harvest, and water yield did increase after logging in WS 1 and 3. Observed annual water yield from WS 1 for 1970-1988 has been 25 percent greater than predicted, after being 31 percent greater immediately following logging (1962-1969, Table 2). However, in streams of the Pacific Northwest most of the increase in annual water yield following logging occurs from October to March, when water is not in short supply (Harr, 1983). Of critical concern to instream biota is water yield in summer.

For WS 1, the period for which increased summer water yield persisted was short, especially considering the proportion of the time that it would represent (8-11 percent) during a rotation time of 70-100 years under intensive forest management. Following the period of increased water yield immediately following logging, timber harvest may actually reduce July and August streamflows for many years. So far the period of reduced yield has been 19 years, or 19-27 percent of the period of a rotation. The actual length of time for which reduced summer flows persist is not known, but they may continue for several decades, until conifers grow large enough to suppress growth of riparian hardwoods, For WS 3, the patch-cut watershed, summertime flows have generally remained at or above prelogging levels (Figure 2B).

The mechanism for different water yield responses of WS 1 and WS 3 following logging and burning is not entirely understood. Reduced evapotranspiration on hillslopes following the start of logging apparently increased delivery of water to the streams for 1962-1969 in WS 1, and for 1963-1978 in WS 3, increasing summer and annual streamflows. However, from 1970 on in WS 1, increased water use by established riparian vegetation may have been responsible for decreased streamflows. An attempt at reducing hardwoods in the riparian zone of WS 1 in 1973 was unsuccessful (pers. comm., F. J. Swanson, Pacific Northwest Research Station, Corvallis, Oregon) and no subsequent increase in water yields was observed. Higher stomatal conductance has been demonstrated in hardwoods such as quaking aspen (*Populus tremuloides* Michx.) in the Rocky Mountains than in conifers (Kaufman, 1984). Thus hardwoods are likely to use more water than conifers in summer for equivalent leaf areas.

Changes in soil moisture in WS 3 were only partly consistent with changes in streamflow. Summer soil moisture in the upper 120 cm of the profile along a transect at a logged site was greater than predicte following logging compared to a transect at a unlogged site from 1963 to 1965. From 1966 to 198 however, soil moisture in summer was less than pre dicted at the logged site (Adams *et al.*, in press), eve though streamflow was consistently greater than pre dicted in WS 3 until 1978 (Figure 2B). This suggest that water stored at depths of >120 cm was responsi ble for the increased streamflows during summer fo lowing logging. If changes in riparian vegetation wer at least partially responsible for the reduced stream flows in WS 1, then replacement of conifers in th streamside zone with hardwoods could have impo tant consequences for aquatic life and downstrea users.

Effects on Salmonid Survival

Summer is a time of stress for juvenile salmonid rearing in streams in the Pacific Northwes Furthermore, streamflows and water temperatur can be factors limiting the survival of aquatic life i streams. Although salmonids do not use the stream i WS 1, we can infer that similar impacts of logging o streams elsewhere, such as in the Oregon Coa Range, would be detrimental. Although hardwood such as red alder in the riparian zone may eventuall shade a stream, they may also bring about detrime tal changes in water quality as well as quantit Leafdrop from hardwoods in dry conditions durin late summer and early fall can contribute to low di solved oxygen concentrations in coastal stream which may reduce growth and survival of fish an invertebrates (Slack, 1955; Hicks, 1990). The extent oxygen depletion was related inversely to streamflo and was greater under red alder than under a mix canopy of bigleaf and vine maple (Hicks, 1990).

Increased temperatures and low dissolved oxyge can have direct effects on fish, causing stress, diseas and consequent mortality. Reduced streamflow ca increase the severity of changes in temperature a dissolved oxygen, and also can have direct and ind rect effects on fish by reducing volume of stream hab tat. Fish may die as a direct result of reduce streamflow as stretches of stream become dry. As indirect effect, reduced flows may increase compe tion among fish. Riffle volumes are affected reduced flows more than glides, and glides are affe ed more than pools (Hicks, 1990). Species such as a 0 steelhead (fry to fingerling-sized *Oncorhynchu mykiss*) often occupy riffles when in the same strea as pool-adapted fish such as age 0 coho salm (*Oncorhynchus kisutch*) (Hartman, 1965; Bisson *al.*, 1988). Thus, with reduced flows juvenile steelhe could be forced out of drying riffles and into poo where they would face increased competition with the more aggressive coho salmon; this is likely to lower the survival of steelhead. In combination with other logging-related habitat changes, such as habitat simplification, decreases in pool habitat, increases in riffle habitat and channel widening (Lyons and Beschta, 1983; Bisson and Sedell, 1984; Tripp and Poulin, 1986; Hicks *et al.*, in press), reduced flows following forest harvest represent another factor that may seriously reduce survival of salmonids.

CONCLUSIONS

Many previous studies of changes in water yield following timber harvest have not fully considered changes in low summer flows. Analysis of logging-related water yield experiments often have looked only at annual water yields, ignoring the critical summer period when evapotranspiration is greatest and water is potentially in short supply. Furthermore, many studies have insufficient periods of record on which to draw conclusions about the long-term effects of logging on water yield (for example, Harris, 1977; Harr *et al.*, 1979; Harr, 1980).

Long-term records from WS 1 (clearcut logged) and WS 2 (unlogged control) in the H. J. Andrews Experimental Forest, spanning nine years before logging and 26 years after logging, show that the relatively large increases in water yield for August following logging were short-lived, existing for only about eight years. After this period, August water yields were less than normal for 18 of 19 years of record. We hypothesize that as a canopy of conifers closes over hardwoods in the riparian zone of WS 1 over the next few decades, the reductions in summer low flow will be eliminated and summer streamflow will return to prelogging levels, possibly 40-60 years after harvest. If the establishment of hardwoods in the riparian zone following clearcut logging has caused water yields in WS 1 to drop below predicted yields, as we suggest, then future forest harvest practices should protect conifers in the riparian zone during logging to suppress hardwood growth and thereby maintain summertime water yields. In view of the importance of the existing hydrological records from WS 1, 2, and 3 in the H. J. Andrews Experimental Forest, continued collection of hydrologic data from these watersheds is imperative.

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LITERATURE CITED

Adams, P. W., A. L. Flint, and R. L. Fredriksen (in press). Long-Term patterns in Soil Moisture and Revegetation After a Clearcut of a Douglas-Fir Forest in Oregon. Forest Ecology and Management.

Azevedo, J. and D. L. Morgan, 1974. Fog Precipitation in Coastal Californian Forests. Ecology 55(5):1135-1141.

Bisson, P. A. and J. R. Sedell, 1984. Salmonid Populations in Streams in Clearcut vs. Old-Growth Forests of Western Washington. *In:* Fish and Wildlife Relationships in Old-Growth Forest, W. R. Meehan, T. R. Merrell, Jr., and T. A. Hanley (Editors). Proceedings of a symposium held in Juneau, Alaska, April 12-15, 1982. American Institute of Fishery Research Biologist, pp. 121-129.

Bisson, P. A., K. Sullivan, and J. L. Nielsen, 1988. Channel Hydraulics, Habitat Use, and Body Form of Juvenile Coho Salmon, Steelhead Trout, and Cutthroat Trout in Streams. Transactions of the American Fisheries Society 117(3):262-273.

Bosch, J. M. and J. D. Hewlett, 1982. A Review of Catchment Experiments to Determine the Effect of Vegetation Changes on Water Yield and Evapotranspiration. Journal of Hydrology 55(1/4):3-23.

Cherry, D. S., K. L. Dickson, and J. Cairns, Jr., 1975. Temperatures Selected and Avoided by Fish at Various Acclimation Temperatures. Journal of the Fisheries Research Board of Canada 32(4):485-491.

Dyrness, C. T., 1973. Early Stages of Plant Succession Following Logging and Burning in the Western Cascades of Oregon. Ecology 54(1):57-69.

Everest, F. H. and J. R. Sedell, 1984. Evaluating Effectiveness of Stream Enhancement Projects. *In:* Proceedings of the Pacific Northwest Stream Habitat Management Workshop, T. J. Hassler (Editor). Held at Humboldt State University, Arcata, California, October 10-12, 1984. Western Division, American Fisheries Society, pp. 246-256.

Elliott, J. M., 1985. Population Dynamics of Migratory Trout, *Salmo trutta*, in a Lake District Stream, 1966-83, and Their Implications for Fisheries Management. Journal of Fish Biology 27(Supplement A):35-43.

Fredriksen, R. L., 1963. A Case History of a Mud and Rock Slide on an Experimental Watershed. U.S. Department of Agriculture Forest Service, pacific Northwest Forest and Range Experiment Station Research Note PNW-1, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 4 pp.

Fredriksen, R. L., 1965. Christmas Storm Damage on the H. J. Andrews Experimental Forest. U.S. Department of Agriculture Forest Service, Pacific Northwest Forest and Range Experiment Station Research Note PNW-29, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 11 pp.

Halpern, C. B., 1988. Early Successional Pathways and the Resistance and Resilience of Forest Communities. Ecology 69(6):1703-1715.

Halpern, C. B., 1989. Early Successional Patterns of Forest Species: Interactions of Life History Traits and Disturbance. Ecology 70(3):704-720.

Harr, R. D., 1980. Streamflow After Patch Logging in Small Drainages Within the Bull Run Municipal Watershed, Oregon. U.S. Department of Agriculture Forest Service Research Paper PNW-268, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 16 pp.

Harr, R. D., 1982. Fog Drip in the Bull Run Municipal Watershed, Oregon. Water Resources Bulletin 18(5):785-789.

Harr, R. D., 1983. Potential for Augmenting Water Yield Through Forest Practices in Western Washington and Western Oregon. Water Resources Bulletin 19(3):383-393.

Harr, R. D., R. L. Fredriksen, and J. Rothacher, 1979. Changes in Streamflow Following Timber Harvest in Southwestern Oregon. U.S. Department of Agriculture Forest Service Research Paper PNW-249, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 22 pp.

Harris, D. D., 1977. Hydrologic Changes After Logging in Two Small Oregon Coastal Watersheds. U.S. Geological Survey Water-Supply Paper 2037, 31 pp.

Hartman, G. F., 1965. The Role of Behaviour in the Ecology and Interaction of Underyearling Coho Salmon (*Oncorhynchus kisutch*) and Steelhead Trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 22(4):1035-1081.

Hicks, B. J., 1990. The Influence of Geology and Timber Harvest on Channel Morphology and Salmonid Populations in Oregon Coast Range Streams. Doctoral Thesis, Oregon State University, Corvallis, Oregon, 199 pp.

Hicks, B. J., J. D. Hall, P. A. Bisson, and J. R. Sedell (in press). Responses of Salmonid Populations to Habitat Changes Caused by Timber Harvest. *In:* The Influence of Forest and Rangeland Management on Salmonids and Their Habitat, W. R. Meehan (Editor). American Fisheries Society, Bethesda, Maryland, Chapter 15.

Isaac, L. A., 1946. Fog Drip and Rain Interception in Coastal Forests. *In:* U.S. Department of Agriculture Forest Service Research Note No. 34. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, pp. 15-16.

Kaufman, M. R., 1984. A Canopy Model (RM-CWU) for Determining Transpiration of Subalpine Forests. I. Model Development. Canadian Journal of Forestry Research 14(2):218-226.

Kovner, J. L., 1956. Evapotranspiration and Water Yield Following Forest Cutting and Natural Regrowth. *In:* Proceedings of the American Society of Foresters. 1956 Annual Meeting, pp. 106-110.

Lyons, J. K. and R. L. Beschta, 1983. Land Use, Floods, and Channel Changes: Upper Middle Fork Willamette River, Oregon (1936-1980). Water Resources Research 19(2):463-471.

Pearce, A. J. and L. K. Rowe, 1979. Forest Management Effects on Interception, Evaporation, and Water Yield. Journal of Hydrology (New Zealand) 18(2):73-87.

Rothacher, J. S., 1970. Increases in Water Yield Following Clear-Cut Logging in the Pacific Northwest. Water Resources Research 6(2):653-658.

Rothacher, J. S., 1971. Regimes of Streamflow and Their Modification by Logging. *In:* Proceedings of a Symposium: Forest Land Uses and Stream Environment, J. T. Krygier and J. D. Hall (Editors). Held October 19-21, 1970, at Oregon State University, Corvallis, Oregon. Forest Extension, Oregon State University, Corvallis, Oregon, pp. 40-54.

Rothacher, J. S., C. T. Dyrness, and R. L. Fredriksen, 1967. Hydrologic and Related Characteristics of Three Small Watersheds in the Oregon Cascades. U.S. Department of Agriculture Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 54 pp.

Slack, K. V., 1955. A Study of the Factors Affecting Stream Productivity by the Comparative Method. Investigations Indiana Lakes and Streams 4:3-47.

Smoker, W. A., 1953. Stream Flow and Silver Salmon Production in Western Washington. Washington Department of Fisheries, Fisheries Research Paper 1(1):5-12.

Tripp, D. B. and V. A. Poulin, 1986. The Effect of Mass Wasting Juvenile Fish Habitats in Streams on the Queen Charlo Islands. Land Management Report 45, British Columl Ministry of Forests, Victoria, British Columbia, 48 pp.

Zar, J. H., 1984. Biostatistical Analysis (2and Edition). Prenti Hall, Englewood Cliffs, New Jersey, 718 pp.

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Seasonal and successional streamflow response to forest cutting and regrowth in the northwest and eastern United States

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[1] This study examined daily streamflow response over up to four decades in northwest conifer forest and eastern deciduous forest sites in the United States. We used novel methods to analyze daily observations of climate and streamflow spanning more than 900 basin years of record at 14 treated/control basin pairs where forest removal and regrowth experiments were underway in the period 1930–2002. In the 1 to 5-year period after forest removal, maximum daily increases ranged from 2 to 3 mm at deciduous forest sites, to 6 to 8 mm at conifer forest sites. Significant spring surpluses persisted for up to 35 years in conifer forest basins, but winter and spring streamflow deficits appeared after 10 to 15 years of forest regrowth in eastern deciduous forest basins. In all 5-yr posttreatment periods, absolute changes in daily streamflow were significantly more likely during moist, warm seasons, or during snowmelt seasons, but relative changes were more likely during warm seasons irrespective of moisture status. Both relative and absolute streamflow changes in the 1 to 5 and 15 to 25-year periods after forest removal were significantly positively related to the age of the forest at the time it was cut. Eastern deciduous forests had been disturbed by logging or hurricane 12 to 56 years prior to forest removal, while Pacific Northwest conifer forests had been not experienced logging or wildfire for 90 to 450 years. Paired basin experiments provide a continuous, and continuously changing, record of vegetation structure, composition, and climate, and their effects on streamflow. *INDEX TERMS:* 1860 Hydrology: Runoff and streamflow; 1803 Hydrology: Anthropogenic effects; 1863 Hydrology: Snow and ice (1827); *KEYWORDS:* Caspar Creek experimental forest, Coweeta experimental forest, Coyote Creek, Fernow experimental forest, H. J. Andrews Forest, Hubbard Brook experimental forest

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1. Introduction

[2] Paired-basin forestry experiments are a major source of data on climate, streamflow, and vegetation for testing of theoretical propositions in hydrology. Yet to date, the hydrologic implications of paired basin experiments have been largely examined for individual experiments, or in reviews or meta-analyses [e.g., *Bosch and Hewlett*, 1982; *Robinson et al.*, 2003] combining results from studies using disparate methods. Hydrologic modeling efforts frequently employ paired-basin data, but inferences are limited by uncertainty about many parameters, including vegetation-climate-soil interactions [*Beven*, 2002].

[3] Studies of eco-physiology, global change, and stream ecology are providing hydrologists with challenging hypotheses about vegetation and climate coupling to hydrology. Eco-physiology studies argue that forest structure and composition develop during succession to reduce stress on plants and optimally use resources, including moisture [*Eagleson*, 2002]. Studies of global change, including climate change, indicate that streamflow responds to changes in temperature and rainfall [*Hodgekins et al.*, 2003] with concurrent changes in vegetation cover and species composition [e.g., *Shafer et al.*, 2001]. Stream ecologists advocate restoration policies based on streamflow variability [*Poff et al.*, 1997], as well as habitat structure. Results from paired-basin experiments can contribute to these issues, by revealing the coupling among vegetation, atmosphere, soil, and streamflow at spatial and temporal scales intermediate between plot- and reach-scale studies characteristic of eco-physiology and stream ecology, and the coarse scales of climate and land use change modeling.

[4] In paired basin experiments, both increases and decreases in streamflow may occur in both relative and absolute terms at different seasons or time periods after treatment, providing clues about causal mechanisms, and geomorphic and ecological consequences, of vegetation change. In published studies, the largest relative changes in streamflow occurred in summer months after removal of eastern deciduous forest [*Douglass and Swank*, 1972, 1975; *Swank et al.*, 2001; *Hornbeck et al.*, 1997; *Martin et al.*, 2000] and western conifer forest [*Rothacher*, 1975; *Harr et al.*, 1979, 1982]. However, in conifer sites, the largest absolute streamflow increases occurred during wet winter months [*Rothacher*, 1970; *Lewis et al.*, 2001]. Lags of

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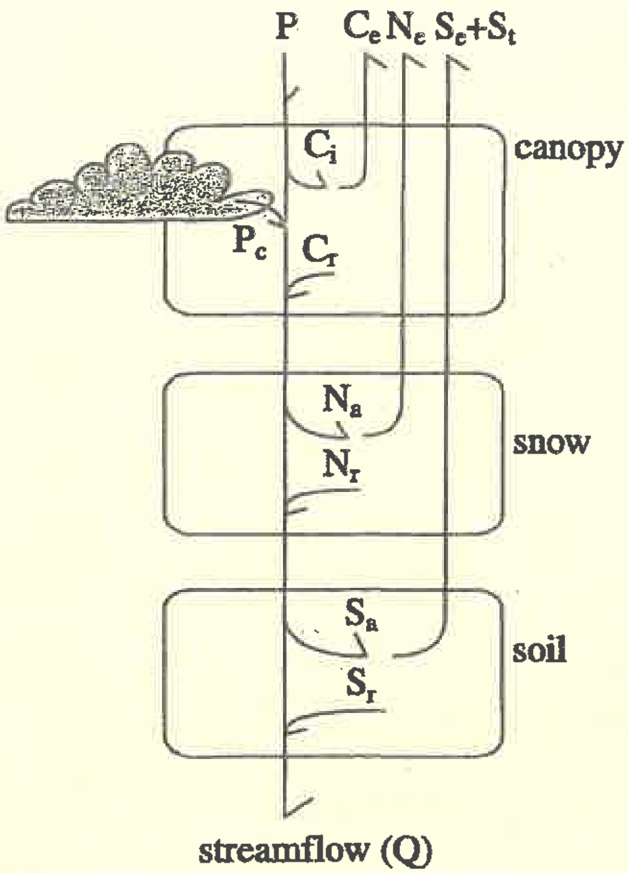

Figure 1. Ten fluxes involving moisture storage reservoirs (boxes) in vegetation canopies, snowpacks, and soils in forested basins. Inputs to the system are from precipitation (P) and cloudwater interception (P_c); output is streamflow (Q). Fluxes into and out of the canopy are interception (C_i), throughfall (C_r) and evaporation (C_e). Fluxes into and out of the snowpack are snow accumulation (N_a), sublimation and evaporation (N_e), and snowmelt (N_r). Fluxes into and out of the soil are soil water accumulation (S_a) and release (S_r), evaporation (S_e) and transpiration (S_t).

several months between periods of vegetation water use and streamflow responses have been reported from southeastern deciduous forest sites [*Swank et al.*, 1988].

[5] Both hydrologic and ecological causal mechanisms have been invoked to explain varied streamflow responses in paired basin experiments. In the northwestern United States, conifer forest removal may modify cloudwater interception [*Harr*, 1982] as well as snowpack dynamics [*Harr*, 1981; *Berris and Harr*, 1987] during wet (winter) seasons. In the eastern United States, vegetation species in early succession may be higher water users per unit leaf area than the species removed, reducing summer streamflows [*Hornbeck et al.*, 1997; *Swank et al.*, 2001]. Also, conifers may use more water over greater periods of the year than deciduous forests, reducing fall, winter, or spring flows [*Swank and Douglass*, 1974; *Swank et al.*, 1988].

[6] Differences among basins where forest removal experiments have been conducted lend themselves to testing the generality of hypotheses about causes and consequences of vegetation change for streamflow. The eastern US has a mesic climate with wet summers whereas the northwestern US has a xeric climate with dry summers. Northern and high-elevation basins have seasonal snow, but basins at lower latitudes or elevations have transient snowpacks or no snow. Basins in the eastern US have deciduous forests mostly regenerating from logging or other disturbances in the early 20th century, whereas basins in the northwestern US have conifer forests that have been protected from logging and wildfire since at least 1900. Thus season, forest type, and forest age, both time since treatment and age of the forest when it was removed, all may influence streamflow response to forest removal.

[7] Technological developments also lend themselves to a broad analysis of paired-basin forest removal experiments [*Jones and Swanson*, 2001]. Records of up to sixty years of continuous streamflow and associated measurements now are available from many sites [*Post et al.*, 1998]. Many of these records are available through online data harvesters (e.g., hydro-DB [*Baker et al.*, 2000]). New methods are being developed for testing hypotheses with long-term streamflow data sets [e.g., *Jones and Grant*, 1996; *Jones*, 2000; *Post and Jones*, 2001]. Finally, increased computer power and growth of the Internet now permit data sets from many sites to be readily compiled and analyzed in one location.

2. Conceptual Model

[8] Hydrologic responses to forest canopy removal and regrowth can be predicted from the hydrologic cycle (Figure 1). Because forest vegetation is coupled to the atmosphere, the snowpack, and the soil, three major classes of hydrologic responses to forest removal and regrowth involve changes in forest canopy interactions with: (1) the atmosphere and soils (i.e., cloudwater interception P_c, canopy interception C_i, evaporation from the canopy and soils C_e and S_e, and transpiration S_t, Figure 1), (2) snowpack accumulation and melt (i.e., snow accumulation N_a, sublimation N_e, and snowmelt N_r, Figure 1), and (3) soil moisture storage (i.e., additions and losses S_a and S_r, Figure 1).

[9] We tested the following hypotheses.

[10] H1. Forest vegetation affects streamflow through evapotranspiration, interception, and soil moisture storage. Therefore streamflow responses to forest removal should occur when temperature is conducive to evapotranspiration, or during periods of snowmelt. Evapotranspiration effects are large in absolute terms at times of year when soils are moist (S_e, S_t, S_a and S_r are large), but they are large in relative terms at times of year when temperature is conducive to transpiration irrespective of soil moisture (S_e and S_t are large but S_a and S_r are small). Snow interception effects are large in absolute terms at times of year when soils are moist and snowmelt is occurring (S_a, S_r, and N_r are large). In sites with cold snowpacks, young deciduous forests produce smaller snowpacks (N_a, N_e, and C_e increase) compared to older deciduous forests, but in sites with warm snowpacks, young conifer forests produce larger snowpacks (N_a, N_e, and C_e decrease) compared to older conifer forests. Alternatively, streamflow responses to forest removal may occur during times of year when neither evapotranspiration nor snowmelt is occurring, because soil moisture storage reservoirs exert a lagged effect.

[11] H2: The forest vegetation effect on streamflow depends upon forest structure and composition, which vary with the age of vegetation. Two measures of forest age are relevant: the age of the forest in the treated basin (time since treatment) and the difference in ages of the forests between the treated and control basins (which is equivalent to the time since most recent pre-treatment forest disturbance). Young forests use more water than older forests at times of year when temperature is conducive to transpiration, irrespective of soil moisture (S_e and S_t are larger relative to S_a and S_r for young than older forests). Therefore streamflow response will decline rapidly in the first few decades of forest regrowth, and forests aged 10 to 30 years will produce summer streamflow deficits relative to older forests. However, as forests age, structure and composition change so as to better utilize water available at times of year when transpiration is temperature- or moisture-limited. Therefore streamflow responses will be positively related to the difference in forest age between the treated and control basins.

3. Study Sites

[12] Study sites were located in six experimental forests, three in the Pacific Northwest of the United States, and three in the eastern United States (Table 1). As of 2002, Pacific Northwest sites (the Andrews, Coyote Creek, and Caspar Creek Experimental Forests) had conifer forests up to 500-yrs old and dry summers. Eastern sites (the Hubbard Brook, Fernow, and Coweeta Experimental Forests) had <100 yr old deciduous forests and wet summers. The northernmost sites (Andrews, Hubbard Brook) had seasonal snowpacks. Mean annual precipitation ranged from 1000 mm to over 2000 mm at both conifer and deciduous sites (Table 1).

[13] Forest age was determined as the time since the most recent severe disturbance documented at that site (Table 1). The most recent disturbances included wildfire and logging in conifer forests, and hurricane and logging in deciduous forest (Table 1). Conifer forest types included western hemlock (Andrews), mixed-conifer (Coyote Creek) and redwood forests (Caspar Creek). Deciduous forest types included northern hardwoods (Hubbard Brook) and oak-hickory forests (Fernow, Coweeta) (Table 1).

[14] Each site consisted of one or more paired-watershed experiments in which 100% of forest cover had been harvested and an unharvested control basin exists (Table 1). Forest harvest treatments at the fourteen treated basins occurred over more than half a century, from the 1930s to 1990 (Figure 2). In ten of these cases forest harvest occurred in a single year, but in four cases harvest occurred over several years (Table 1, Figure 2). Treatment involved logging (removal of wood products) in ten treated watersheds. In four cases wood products were not removed, and in two of these four cases herbicide was applied for several years after logging (Table 1). Because of differing disturbance histories, 90 to 450 yr-old forests were removed in the conifer sites, but 12 to 56 yr-old forests were removed in the deciduous forest sites (Table 1).

[15] Long-term records of streamflow and climate have been collected at 26 basins (14 treated, 12 control) from the six study sites. Basin size ranged from 9 to 96 hectares, and streamflow and climate records span periods ranging from 17 years to 63 years (Figure 2). Pre-treatment records were 6 or more years in length in all but one treated basin, and posttreatment records ranged from 11 to over 40 years (Figure 2). Most of the basins ranged in size from 20 to 50 ha, and the ages of most harvested forest ranged from 30 to 125 years (Table 2, Figure 2).

4. Methods

4.1. Datasets and Data Collection

[16] Mean daily streamflow, precipitation, minimum and maximum temperature, and snowpack data from five of the six sites are publicly available on the worldwide web and were collected electronically through Hydro-DB, an automated data harvester http://www.fsl.orst.edu/hydrodb/). Data from the sixth site (Coweeta Experimental Forest) are not publicly available, but they were provided by U.S. Forest Service scientists (L. Swift and W. Swank) for periods of record through 1995. The resulting primary data set consisted of over 750,000 observations spanning more than 900 watershed-years of streamflow records. Original streamflow data in units of L/s were converted to mm/day (unit area discharge):

$$\frac{mm}{day} = 8.64 \cdot \frac{L}{s} \cdot A$$

where A is basin area in hectares. We used a water year from 1 October to 30 September. For Caspar Creek many values from late April to early November were missing values.

[17] The initial data set comprised records from 26 basins (14 treated, 12 control). We present results from 14 treated/control pairs (Table 2). In 11 of these 14 pairs we used the treated/control pairs established by the original researchers. In three cases, we used an alternative to the original control basin (Table 2). In these three cases, Coweeta 7/34 (7/2), Coweeta 13/14 (13/18), and Andrews 10/2 (10/9), the original control basins (in parentheses) were less than 15 ha in size. The average standard deviation of daily flow at control basins in mm (y) was significantly negatively related to basin size in hectares (x) ($y = 2.29 \exp(-0.034x)$; $r^2 = 0.84$; $n = 12$). Therefore streamflow changes were not detectable using the original (<15 ha) basins, but they were detectable when the same treated basins were compared to larger, nearby control basins. Moreover, in one case (Andrews 10/9) the original treated/control relationship was suspect because a flume change 15 months prior to the treatment produced significant changes in streamflow at the control basin (Andrews 9).

4.2. Calculating Streamflow Responses to Forest Removal and Regrowth

[18] The change in streamflow in the treated basin relative to the pretreatment treated/control relationship was calculated by day of year and averaged for 5-yr periods after forest removal, following *Jones and Grant* [1996] and *Jones* [2000]. The treated/control relationship was

$$c_{ij} = \ln\left[\frac{(b_{ij})}{(a_{ij})}\right]$$

where c_{ij} = the (ln-transformed) ratio of streamflow at the treated and control basins, day i, year j; a_{ij} and b_{ij} = unit area

Table 1. Vegetation Cover, Disturbance History, Treatments, and Ages of Forest in Fourteen Treated/Control Basin Pairs in This Study

Basin Pair	Disturbance	Treatment Type	Treatment Date	Age[a] Treated[b]	Age[a] Control[c]	MAP,[a] mm
		Western Hemlock[d]				
Andrews 1/2	severe wildfire in 1500s	100% clearcut, logged, burn	1962–66	450	500	2270
Andrews 6/8	wildfire in 1500s, 1850s	100% clearcut, logged, road	1974	125	150	2178
Andrews 10/2	"	100% clearcut, logged	1975	125	500	2282
		Mixed Conifer[e]				
Coyote 3/4	wildfire in 1500s, 1850s	100% clearcut, logged	1970	120	145	984
		Redwood[f]				
Caspar C/I	clearcut, logged 1860–1904	96% clearcut, logged	1991	90	100	1190
Caspar E/I	"	100% clearcut, logged	1991	90	100	1190
		Northern Hardwood[g]				
Hubbard Brook 2/3	logged 1800s–1910, hurricane/salvage 1938	100% clearcut, herbicide	1965	27	64	1312
Hubbard Brook 4/3	"	100% clearcut, logged	1970–74	32	64	1312
Hubbard Brook 5/3	"	100% clearcut, logged	1983	45	64	1312
		Oak-Hickory[h]				
Fernow 1/4	logged 1905–1910	100% clearcut, logged	1957	50	95	1438
Fernow 7/4	"	100% clearcut, herbicide	1963	56	95	1450
		Oak-Hickory[i]				
Coweeta 7/34	grazing, burning 1840–1906; logged 1919–27	100% clearcut, logged	1977	50	75	1962
Coweeta 13/14	"	100% clearcut	1939	12	75	1934
Coweeta 37/36	"	100% clearcut	1963	35	75	2191

[a]Age of forest (time since last forest disturbance) and mean annual precipitation (mm) at the control basin for the period of record used in the analysis. Forest ages are based on *Weisberg and Swanson* [2003] (Andrews), *Lewis et al.* [2001] (Caspar Creek), *Douglass and Hoover* [1988] (Coweeta), *Harr et al.*, [1979] (Coyote), Fernow Experimental Forest website (http://www.fs.fed.us/ne/parsons/fefhome.htm), *Schwarz et al.* [2001] (Hubbard Brook). Ages of 500-year old forest have error margins of ±25 years due to uncertainty in dating prehistorical events. Forest ages were log-transformed in analyses in part to account for increasing uncertainty of dates with forest age.

[b]Age (time since last forest disturbance) of forest in treated basin at time of treatment.

[c]Age (time since last forest disturbance) of forest in control basins in 2002.

[d]Forests dominated by Douglas-fir (*Pseudotsuga menziesii*) with western hemlock (*Tsuga heterophylla*) and red cedar (*Thuja plicata*) [*Rothacher et al.*, 1967].

[e]Forests dominated by Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), and sugar pine (*Pinus lambertiana*) [*Harr et al.*, 1979].

[f]Forests dominated by coast redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*) and western hemlock (*Tsuga heterophylla*) [*Lewis et al.*, 2001].

[g]Forests dominated by American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), and yellow birch (*Betula alleghaniensis*) [*Schwarz et al.*, 2001].

[h]Forests dominated by northern red oak (*Quercus rubra*), sugar maple (*Acer saccharum*), and tulip poplar (*Liriodendron tulipifera*) (Fernow web site).

[i]Forests dominated by chestnut oak (*Quercus prinus*), scarlet oak (*Quercus coccinea*), northern red oak (*Quercus rubra*), red maple (*Acer rubrum*), and tulip poplar (*Liriodendron tulipifera*) with abundant rhodedendron (*Rhodedendron maximum*) [*Day et al.*, 1988].

streamflow (mm) at the control basin and the treated basin, respectively, on day i, year j. The period of record was divided into periods k = 1, 2,. . .n, such that the pretreatment period was noted 1, and 5-year posttreatment periods were noted 2 and higher. The average treated/control relationship was

$$c_{ik} = \overline{c_{ij}}$$

for years j in period k = 1, 2, .n. The percent change in the treated/control relationship in a given posttreatment period relative to the treated/control relationship in the pretreatment period, for each period k, was

$$d_{ik} = \left(\exp^{(c_{ik}-c_{i1})} - 1\right) \cdot 100$$

for periods k = 2,. . .n and where d_{ik} = percent change on day i, years j in period k, c_{ik} = treated/control relationship on day i, years j in 5-yr posttreatment period k, c_{i1} = treated/control relationship on day i, years j in the pretreatment period. The mean of (log-transformed) daily flow at the control basin on day i for period k was:

$$e_{ik} = \sum_{j \in k} \ln(a_{ij})/n_k$$

where n_k = number of years in period k. The absolute change in streamflow (back-transformed to units of mm/day) in the treated basin relative to the control basin on day i of 5-yr posttreatment period k was:

$$f_{ik} = d_{ik} \cdot \exp(e_{ik})$$

The detection of change in paired-based experiments depends fundamentally upon ratios, whose interpretation can be problematic when the denominator (flow at the control basin) is a small number. Several measures were taken in the analysis and presentation of results to protect

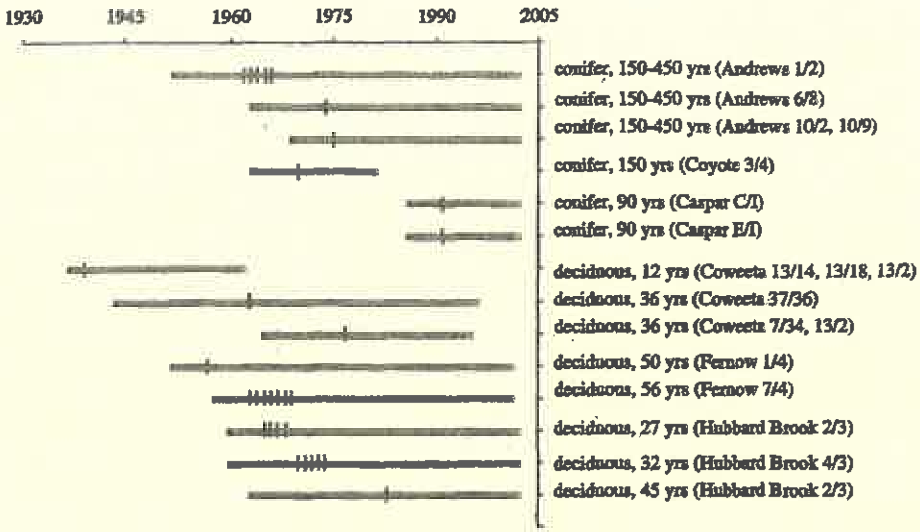

Figure 2. Periods of record of the fourteen small paired-watershed experiments examined in this study. Vertical lines indicate dates of forest harvest and herbicide treatments (where relevant). Experiments are arranged by forest type (conifer, deciduous) in the treated/control pair and age (time since most recent forest disturbance) of the treated watershed. Vertical lines indicate the date of forest removal. Some treatments lasted for multiple years: forests were harvested over 5 yrs at Andrews 1, Fernow 7 and Hubbard Brook 4; herbicide was applied for 3 years at Hubbard Brook 2 and Fernow 7. Some treated watersheds (Andrews 10, Coweeta 7, Coweeta 13) were compared to more than one control watershed.

against misleading interpretations from ratios. Streamflow data were filtered before analysis to remove very low flows. Days with streamflow less than 0.01 mm were treated as missing values, and streamflow changes were calculated only for days with less than two missing values in any five-year posttreatment period. Both absolute and relative changes were calculated to identify instances where very large relative changes were small in absolute terms. Relative changes (d_{ik}) and absolute changes (f_{ik}) were smoothed with a 15-day window to reduce the effect of large changes on any given day, and figure axes were restricted to exclude the occasional values that are improbably large. Statistical analyses were either non-parametric tests based on counts of days exceeding some threshold of d_{ik} and f_{ik}, or regressions of average percent changes by season rather than daily values.

4.3. Hypothesis Tests

[19] Hypotheses involving seasons were tested using chi-squared tests of independence of streamflow changes by season [*Ramsay and Schaefer*, 1996]. Days with absolute streamflow changes were tested for independence to (1) moist periods when temperatures are conducive to evapotranspiration, and (2) snowmelt periods. Days with

Table 2. Eighteen Treated/Control Basin Pairs Examined in This Study

Treated/Control Basin Pair	Basin Size, ha		Streamflow Record, Years		
	Treated	Control	Total	Pretreatment	Posttreatment
Andrews 1/2[a]	96	60	1953–2002	9	41
Andrews 6/8[a]	15	22	1964–2002	10	28
Andrews 10/2[a]	10	60	1969–2002	6	27
Andrews 10/9	10	9	1969–2002	6	27
Caspar C/I[a]	26	21	1986–2002	6	11
Caspar E/I[a]	27	21	1986–2002	6	11
Coyote 3/4[a]	49	50	1964–81	6	11
Coweeta 7/2	59	13	1965–96	12	20
Coweeta 7/34[a]	59	33	1965–96	12	20
Coweeta 13/2	16	12	1937–62	2	23
Coweeta 13/14[a]	16	61	1937–62	2	23
Coweeta 13/18	16	13	1937–62	2	23
Coweeta 37/36[a]	44	49	1944–96	20	43
Fernow 1/4[a]	30	39	1951–2001	6	44
Fernow 7/4[a]	29	39	1957–2001	6	38
Hubbard Brook 2/3[a]	16	42	1958–96	7	31
Hubbard Brook 4/3[a]	36	42	1958–96	12	26
Hubbard Brook 5/3[a]	22	42	1958–96	25	13

[a]Results from fourteen basin pairs are examined in detail.

Table 3. Seasons, Defined by Dates, Discharge, Runoff Ratio, Minimum and Maximum Temperatures From Control Basins[a]

Control Basin	Moist: Cool	Moist: Snow Accumulation	Moist: Snowmelt	Dry or Moist Warm	Water Year
		Andrews 2			
Dates	10/1–12/7	12/8–2/8	2/9–6/12	6/13–9/30	10/1–9/30
Discharge, mm	230	525	546	44	1344
Runoff ratio, %	36	74	72	28	59
Min temperature, °C	3	−1	3	10	4
Max temperature, °C	9	4	13	25	14
		Andrews 8			
Dates	9/11–12/6	12/7–2/10	2/11–6/24	6/25–9/10	10/1–9/30
Discharge, mm	178	434	524	23	1160
Runoff ratio, %	28	67	70	24	53
Min temperature, °C	4	−1	4	11	5
Max temperature, °C	12	5	14	26	14
		Andrews 9			
Dates	9/12–12/2	12/3–3/2	3/3–3/27	3/28–9/11	10/1–9/30
Discharge, mm	190	690	128	213	1222
Runoff ratio, %	31	70	66	45	54
Min temperature, °C	4	−1	−1	8	4
Max temperature, °C	11	4	6	21	14
		Coyote 4			
Dates	11/5–12/25	12/26–2/4	2/5–5/20	5/21–11/4	10/1–9/30
Discharge, mm	124	162	201	24	511
Runoff ratio, %	51	115	57	10	52
Min temperature, °C	1	0	3	9	5
Max temperature, °C	7	6	12	22	15
		Caspar 1			
Dates	11/23–4/24	–	–	4/25–11/22	10/1–9/30
Discharge, mm	32	–	–	415	447
Runoff ratio, %	12	–	–	46	38
Min temperature, °C	10	–	–	6	8
Max temperature, °C	19	–	–	12	16
		Hubbard Brook 3			
Dates	–	10/1-3/16	3/17–5/15	5/16–9/30	10/1–9/30
Discharge, mm	–	346	348	144	837
Runoff ratio, %	–	58	171	28	63
Min temperature, °C	–	−7	0	11	−3
Max temperature, °C	–	2	10	21	6
		Fernow 4			
Dates	10/11–4/30	–	–	5/1–10/10	10/1–9/30
Discharge, mm	486	–	–	156	642
Runoff ratio, %	63	–	–	23	44
Min temperature, °C	−2	–	–	11	4
Max temperature, °C	8	–	–	23	15
		Coweeta 14			
Dates	10/17–4/17	–	–	4/18–10/16	10/1–9/30
Discharge, mm	578	–	–	385	962
Runoff ratio, %	57	–	–	49	54
Min temperature, °C	0	–	–	12	6
Max temperature, °C	14	–	–	26	20
		Coweeta 34			
Dates	10/17–4/17	–	–	4/18–10/16	10/1–9/30
Discharge, mm	658	–	–	509	1167
Runoff ratio, %	59	–	–	58	59
Min temperature, °C	0	–	–	12	6
Max temperature, °C	14	–	–	26	20
		Coweeta 36			
Dates	10/17–4/17	–	–	4/18–10/16	10/1–9/30
Discharge, mm	1100	–	–	587	1687
Runoff ratio, %	89	–	–	61	77
Min temperature, °C	0	–	–	12	6
Max temperature, °C	14	–	–	26	20

Table 4. Numbers of Treated/Control Basin Pairs by Basin Type[a]

	>100 Year-Old Conifer Forest, Dry Summer	<95 Year-Old Deciduous Forest, Wet Summer	Number of Pairs
Seasonal snowpack	Andrews 1/2 Andrews 6/8	Hubbard Brook 2/3 Hubbard Brook 4/3 Hubbard Brook 5/3	5
Transient snow or no snow	Andrews 10/2 Coyote 3/4 Caspar C/I Caspar E/I	Fernow 1/4 Fernow 7/4 Coweeta 7/34 Coweeta 13/14 Coweeta 37/36	9
Number of pairs	6	8	14

[a]Types are conifer, no seasonal snow; conifer, seasonal snow; deciduous, no seasonal snow; deciduous, seasonal snow. Basin types are based on vegetation type and forest age in control basin as of 2002 (time since most recent forest disturbance), summer precipitation, and presence/absence of a seasonal snowpack. A seasonal snowpack persists throughout the winter, whereas a transient snowpack may persist for only a few days to a few weeks [*Harr*, 1981]. Snow seasonality is based on long-term records (snow data at Hubbard Brook) and modeling [*Perkins*, 1997].

relative streamflow changes were tested for independence to warm periods. For each period k, absolute streamflow changes were defined as all days i for which the 15-day smoothed values of

$$f_{ik} > s[\ln(a_{ij})]$$

where $s[\ln(a_{ij})]$ was the back-transformed, smoothed standard deviation of a_{ij} for all years j in the period of record. Thus $n_{abs,k}$ is the count of days i in the water year for which f_{ik}, the absolute change in the treated/control relationship days in period k, exceeds the variation in the entire record of streamflow on that day at the control watershed. Relative streamflow changes were defined as all days i for which the 15-day smoothed values of

$$d_{ik} > 25$$

Thus $n_{rel,k}$ is a count of days i in the water year on which the treated/control relationship in streamflow in period k changed by more than 25%.

[20] Counts of days with absolute and relative changes ($n_{abs,k}$, $n_{rel,k}$) were subdivided by season. Every day of the water year at each control basin was classified into one of four seasons based on soil moisture, temperature, and snowmelt (Table 3). Two seasons occurred at basins lacking snowpacks: (1) warm (and dry at conifer basins, moist at deciduous basins), and (2) moist, cool. Basins with snowpacks had two additional seasons: (3) moist, snow accumulation and (4) moist, snowmelt. Seasons were defined based on mean values over the entire period of record at each control basin for each day i of minimum and maximum temperatures ($T_{min,i}$, $T_{max,i}$), precipitation (P_i), streamflow (Q_i), and snow water equivalent (S_i). Warm, moist periods were defined as all days i for which $T_{min,i} > T^*_{min}$, $P_i > P^*$, and $Q_i > Q^*$, where T^*_{min} is a temperature threshold of 5°C for deciduous forests and 0.1°C for conifer forests, and P^* and Q^* are moisture thresholds of 2 mm and 0.5 mm, respectively. Warm periods were defined as all days i for which $T_{min,i} > T^*_{min}$, and (for warm, dry periods at conifer basins) $P_i < P^*$ and $Q_i < Q^*$. Periods in which snowpacks were present were divided into days for which $S_i > S_{i-1}$ (accumulation) or $S_i < S_{i-1}$ (melt).

[21] Hypotheses involving succession were tested by linear regression [*Ramsay and Schaefer*, 1996]. Response variables were the sum of daily streamflow changes f_{ik} by season and for the whole water year, and these sums as percents of seasonal or annual streamflow (Table 3). The independent variable was the difference in age between the control and treated basin (Table 1). Data points in regressions were coded by basin types: (1) conifer, seasonal snow; (2) conifer, transient or no snow; (3) deciduous, seasonal snow; (4) deciduous, transient or no snow (Table 4).

5. Results

5.1. Summer Precipitaton and Snowmelt Effects on Daily Streamflow

[22] Daily streamflow responds to summer precipitation and snowpack characteristics of the basins. The Pacific Northwest (conifer forest) has dry summers, whereas the east (deciduous forest) has wet summers (Tables 3 and 4, Figure 3). In conifer forest basins with transient or no snow (Andrews 9, Coyote 4, Caspar I), smoothed daily streamflow peaks in January or February and declines rapidly starting in March, as precipitation declines and minimum temperatures rise above 0°C. In deciduous forest basins with transient or no snow (Fernow, Coweeta), streamflow peaks in March, just before leafout, and declines rapidly, despite constant precipitation, after minimum temperatures rise above 5°C. In conifer basins with seasonal snow (Andrews 2, Andrews 8), streamflow remains elevated after snowmelt in March, April, and May (Figure 3). In the deciduous forest basin with a seasonal snowpack (Hubbard Brook), streamflow declines after December as the snowpack forms, rises to a maximum in mid-April during snowmelt, begins to decline in late April, and continues to decline rapidly after minimum temperatures rise above 5°C in May (Figure 3).

5.2. Seasonal Effects

[23] Large streamflow changes, in both absolute and relative terms, were associated with vegetation change, but they occurred during different seasons and time periods in various basin pairs. Absolute changes in daily streamflow after 100% forest removal were strongly seasonal, and ranged from slight decreases of up to −2 mm/day, to no change at all, to increases of as much as 8 mm/day (Figure 4). In conifer forest basins, daily streamflow increased by as much as 6 to 8 mm during the fall, and 2 to 6 mm in the winter and spring, in the 1 to 5-yr period after forest removal. Some increases persisted for up to 35 years. In deciduous forest basins, streamflow changes were both positive and negative, and occurred during summer, snowmelt, and other periods. Except in one herbicided basin where initial increases were larger

Note to Table 3

[a]Dates are given in month/day. Seasons are defined in the text. Runoff ratio is streamflow/precipitation × 100. The warm season is moist in eastern forests, and dry in Pacific Northwest forests.

Table 5. Absolute Streamflow Changes in Warm, Moist Seasons After Forest Removal and During Forest Regrowth at Fourteen Pairs of Small Experimental Basins in Pacific Northwest Conifer and Eastern Deciduous Forests, USA[a]

		Years After Forest Removal								
Hypothesis/Season	Treatment	1 to 5	6 to 10	11 to 15	16 to 20	21 to 25	26 to 30	31 to 35	36 to 40	41 to 45
Conifer Forests										
Andrews 1/2										
Change (mm)	318	414	293	229	246	238	197	152		
Odds ratio	5[b]	203[d]	8[d]	7[d]	13[d]	6[d]	6[d]	4[c]		
Andrews 6/8										
Change (mm)		421	237	240	268	205	104			
Odds ratio		1	2	43[d]	2[b]	2	7[b]			
Andrews 10/2										
Change (mm)		108	95	91	−16	−30	−31			
Odds ratio		4[c]	7[d]	10[d]	3[b]	4[b]	2			
Coyote 3/4										
Change (mm)		265	284							
Odds ratio		5[d]	8[d]							
Caspar C/I										
Change (mm)		196	274							
Odds ratio		–	–							
Caspar E/I										
Change (mm)		124	520							
Odds ratio		–	–							
Deciduous Forests										
Hubbard Brook 2/3										
Change (mm)	661	262	51	−17	−21	−25	−59	4		
Odds ratio	7[d]	3[b]	0.4	0.4	0.1	0.2	0.2	0.2		
Hubbard Brook 4/3										
Change (mm)		101	79	37	−36	−61	−61	−51		
Odds ratio		0.1	0.1	–	0.1	0.1	0.3	0.2		
Hubbard Brook 5/3										
Change (mm)		131	87	0	−27					
Odds ratio		0.4	0.3	0.2	0.3					
Fernow 1/4										
Change (mm)		156	16	16	27	34	52	2	−8	
Odds ratio		48[d]	0.1	–	0.1	4	1.6	0.1	–	
Fernow 7/4										
Change (mm)	66	149	60	9	−16	−5	8	−38		
Odds ratio	–	–	–	–	–	–	–	–		
Coweeta 7/34										
Change (mm)		105	1	−57	86					
Odds ratio		0.2[c]	0.1[b]	4[b]	3[b]					
Coweeta 13/14										
Change (mm)		17	14	−28	−39	−63				
Odds ratio		0.8	0.5	0.2[d]	0.6	4[c]				
Coweeta 37/36										
Change (mm)		164	61	55	–	−28	−46	−47		
Odds ratio		13[d]	2	3[b]	–	0.1[b]	0.5	0.3[b]		

[a] Change and odds ratios are shown for each basin pair and postharvest time period. Blanks indicate no data for that time period. Dashes indicate that no chi-squared test could be conducted, because one or more cells of the 2 × 2 table contained no observations. An odds ratio >1 means that days with an absolute streamflow response were more likely to occur during the warm, moist season, and an odds ratio <1 means that days with an absolute streamflow response were less likely to occur during the warm, moist season.

[b] Chi-squared tests of independence between absolute streamflow changes and the warm, moist season were significant at $p < 0.05$.

[c] Chi-squared tests of independence between absolute streamflow changes and the warm, moist season were significant at $p < 0.001$.

[d] Chi-squared tests of independence between absolute streamflow changes and the warm, moist season were significant at $p < 0.0001$.

(Figure 4g), daily streamflow in deciduous basins increased by no more than 2 to 3 mm in the 1 to 5-yr period after forest removal. After a decade of forest regrowth, streamflow surpluses became deficits in several deciduous basins.

[24] Relative changes in daily streamflow after 100% forest removal also were strongly seasonal, and ranged from initial increases of a few tens to hundreds of percent (Figure 5). In conifer forest basins, daily streamflow increased by several hundred percent during the late summer/early fall (and late spring, at Caspar Creek, but results are affected by missing data) in the 1 to 5-yr period after forest removal. By 25 to 35 years after forest removal, maximum summer deficits ranged from −30 to −50% (Figure 5). In deciduous forest basins, daily streamflow increases ranged from more than several hundred percent (in herbicided basins), 200–300% (at Hubbard Brook and Fernow), to a few tens of percent (Coweeta), in late summer and early fall in the 1 to 5-yr period after forest removal. By 25 to 35 years after forest removal, maximum summer streamflow deficits ranged from −50% (Hubbard Brook and Fernow) to −30% (Coweeta) (Figure 5).

[25] Seasons were accurate predictors of when streamflow change occurred. Absolute streamflow change was significantly associated with warm moist periods in three of

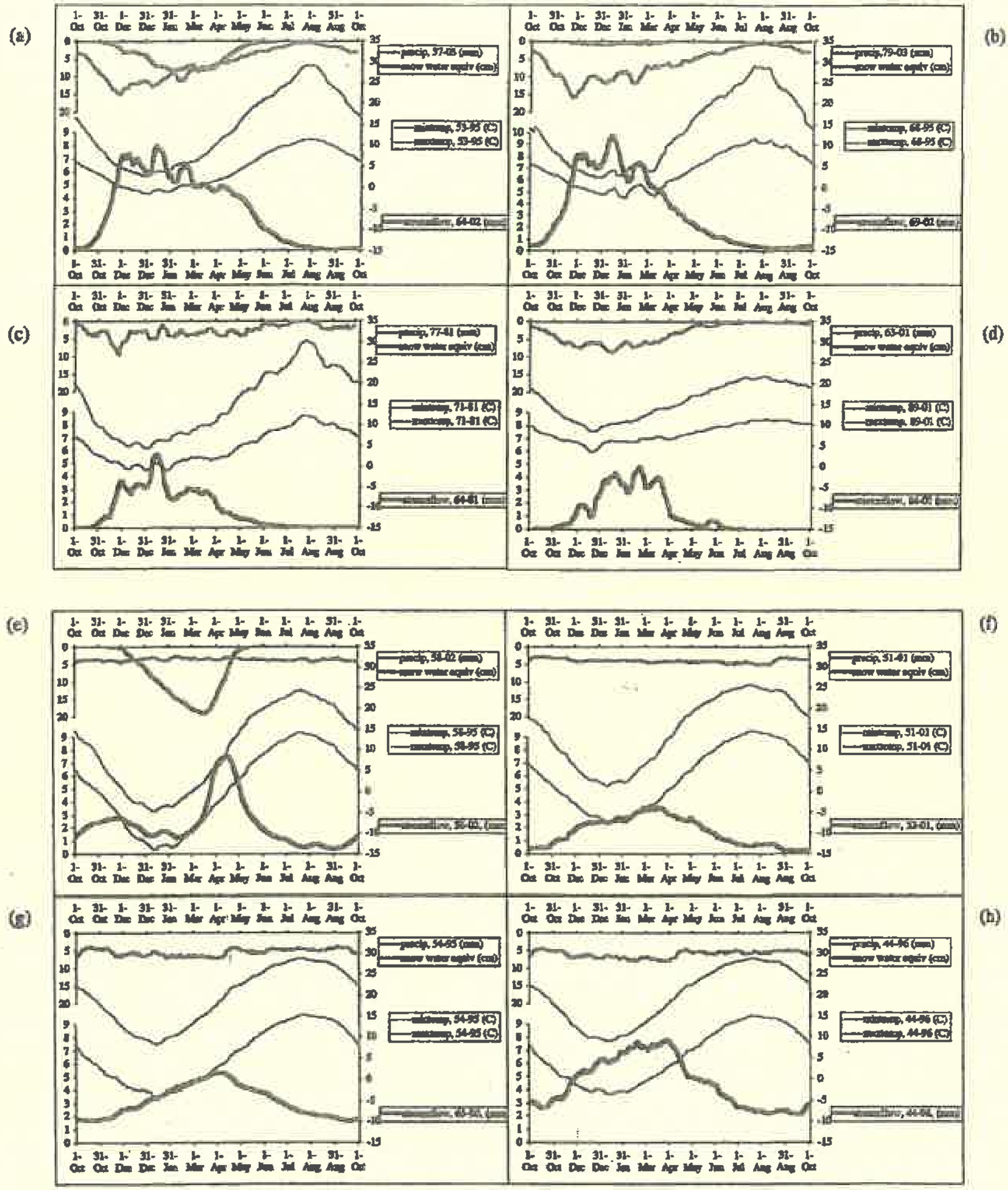

Figure 3. Mean daily precipitation (mm), snowpack (mm of snow water equivalent), streamflow (mm), maximum and minimum temperatures (°C) in ten control basins used in this study. Forest type (conifer versus deciduous), presence/absence of seasonal snowpack, and forest age in 2002 are noted. (a) Conifer, seasonal snow, 500 and 150 years (Andrews 2, Andrews 8); (b) conifer, transient/no snow, 150 years (Andrews 9); (c) conifer, transient/no snow, 150 years (Coyote 4); (d) conifer, no snow, 100 yrs (Caspar I); (e) deciduous, seasonal snow, 64 years (Hubbard Brook 3); (f) deciduous, transient snow, 95 years (Fernow 4); (g) deciduous, no snow, 75 years (Coweeta 2); (h) deciduous, no snow, 75 years (Coweeta 36).

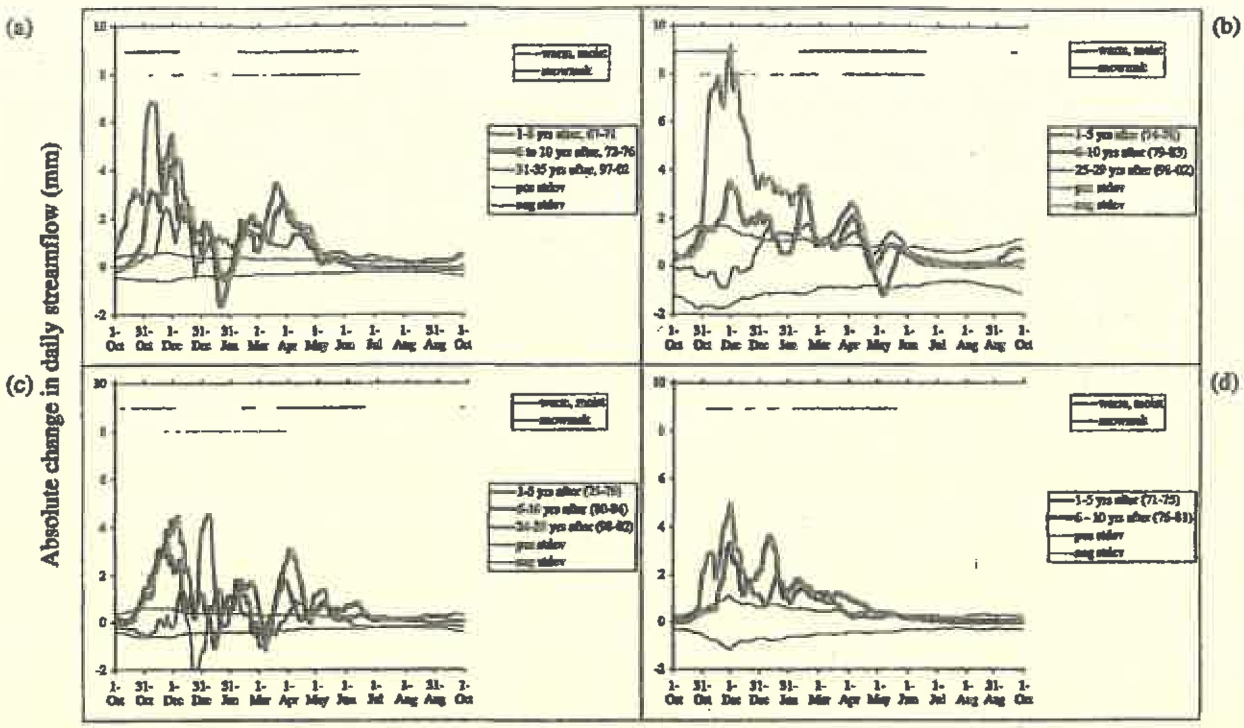

Figure 4. Absolute change in daily streamflow (mm) by day of water year (1 October - 30 September) for 5-year periods after forest removal at fourteen treated/control basin pairs. At the six conifer forest pairs, forest age (time since most recent forest disturbance) and snow conditions were (a) 462 year-old Douglas-fir/western hemlock forest, seasonal snow (Andrews 1/2); (b) 125-to 450-year old Douglas-fir/western hemlock forest, seasonal snow (Andrews 6/8); (c) 125 year old Douglas-fir/western hemlock forest, transient snow (Andrews 10/2); (d) 125-year old mixed-conifer forest, transient/no snow (Coyote 3/4); (e) 90-year old coast redwood/Douglas-fir forest, no snow (Caspar C/I); (f) 90-year old coast redwood/ Douglas-fir forest, no snow (Caspar E/I). At the eight deciduous forest pairs, forest age (time since most recent forest disturbance) and snow conditions were (g) 27 year-old deciduous forest, seasonal snow (Hubbard Brook 2/3); (h) 32 year old deciduous forest, seasonal snow (Hubbard Brook 4/3); (i) 45 year old forest, seasonal snow (Hubbard Brook 5/3); (j) 50-year old red oak/sugar maple forest, transient/no snow (Fernow 1/4); (k) 56-year old red oak/sugar maple forest, transient/no snow (Fernow 7/4); (l) 50-year old deciduous forest, no snow (Coweeta 7/34); (m) 12-year old deciduous forest, no snow (Coweeta 13/14); (n) 36-year old deciduous forest, no snow (Coweeta 37/36).

four conifer basins, whereas absolute changes for the most part were independent of warm, moist seasons in the deciduous forest basins (Table 5). Days with absolute streamflow changes were three to many times more likely to occur during warm, moist periods than other periods in these six basin pairs, but they were no more, or slightly less likely to occur during warm moist periods in four deciduous forest basins. Net increases of 100 to 400 mm occurred in fall and spring in conifer forest basins, and net increases of 100 to 200 mm occurred in summer in deciduous forest basins (Table 5).

[26] Relative streamflow change was significantly associated with warm periods in all basins (Table 6). Relative streamflow changes in the 1 to 5-yr period after forest removal were significantly associated with periods of warm temperatures (summer), and amounted to net increases of 5 to 200% of summer flows (Table 6). However, in one case involving removal of 12-yr old forest (Coweeta 13/14), relative streamflow responses were not associated with season, and in another case (Coweeta 7/34), relative streamflow changes were significantly associated with cold periods. In conifer forest basins, summer streamflow changes disappeared by 5 to 10 years after forest removal. By 25 to 35 years after forest removal in conifer forest basins, a significantly higher than expected number of days had summer streamflow deficits exceeding −25%, but the net changes in summer streamflow ranged from +6 to −48% (Table 6). In contrast, streamflow changes were significantly more likely during the summer in all periods after forest removal in most of the deciduous forest basins, but the net changes in summer streamflow ranged from +33% (Fernow 1/4) to −42% (Hubbard Brook 2/3) (Table 6).

[27] In basins with snowpacks, absolute streamflow changes were significantly associated with periods of snowmelt in all 5-yr periods after forest removal (Table 7). In conifer forest basins with seasonal snowpacks (Andrews 1/2 and 6/8), these changes amounted to net increases of 100 to 200 mm during the snowmelt period (Table 7). In the conifer forest basin with a transient snowpack (Andrews 10), initial streamflow surpluses became streamflow deficits relative to the control, which has a seasonal snowpack (Andrews 2). In the deciduous forest basins, streamflow deficits occurred

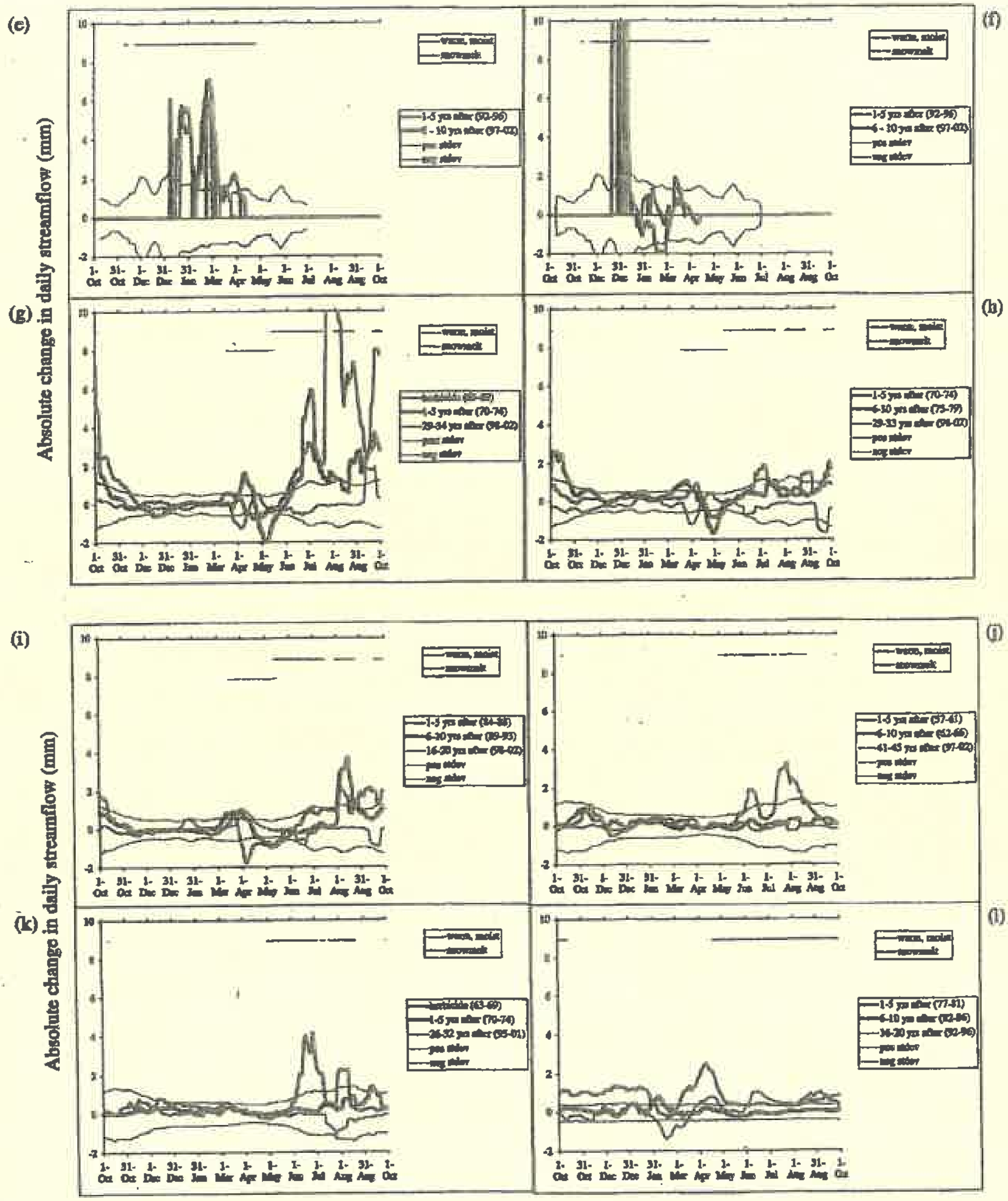

Figure 4. (continued)

during the snowmelt period; net changes ranged from +19 to −47 mm.

5.3. Successional Effects

[28] Streamflow responses to forest removal were related to two aspects of forest succession: (1) age of the regenerating forest (i.e., time since treatment, Figure 6), and (2) the difference in forest age between the treated and control basins (Figure 7). Streamflow responses to forest removal declined over several decades of forest regrowth, but the rate of decline varied by season and forest type and age, and there is considerable between-site variability in response for any given posttreatment period (Figure 6). For the entire water year, streamflow surpluses were highest and most persistent after removal of 90 to 450-yr old conifer forests, and lowest and most ephemeral after removal of

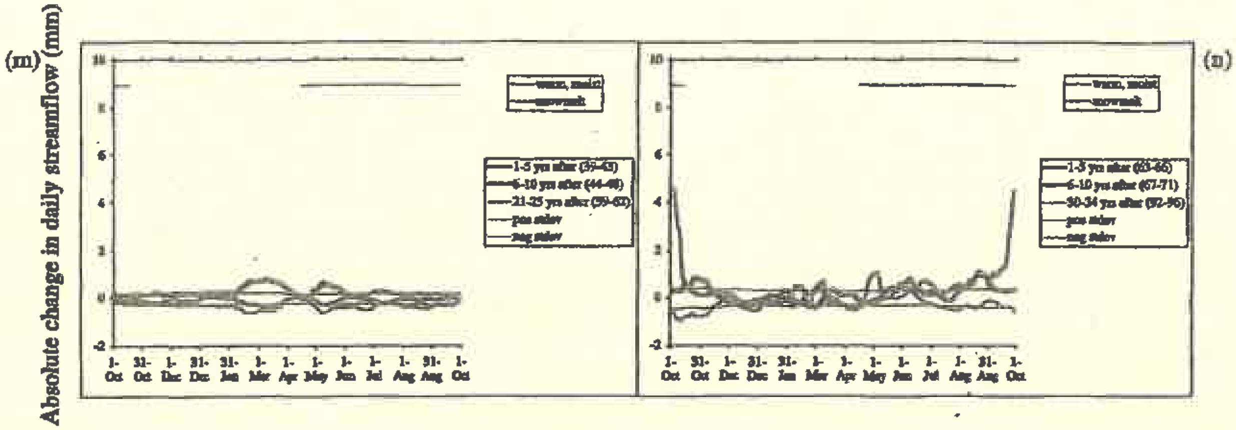

Figure 4. (continued)

12 to 56-yr old deciduous forests (Figure 6a). Conifer forests with transient snow or no snow had intermediate responses in annual streamflow. Surpluses during the snowmelt period persisted for up to four decades after removal of conifer forests from basins with a seasonal snowpack (Figure 6b). Streamflow surpluses in warm, moist seasons were higher and more persistent in conifer forest basins compared to deciduous forests (Figure 6c). By 20–25 years after forest removal (period 5), streamflow deficits had developed in August in all but one treated basin (Figure 6d). Although absolute changes were small, August streamflow 15 years after forest removal had declined by 60 to 80% relative to pretreatment August streamflow (Figure 6d).

[29] The age of forest at the time it was harvested (which is equivalent to the difference in age between the forest in the control and the treated basin) explains additional variability in streamflow response beyond that explained by season or time since treatment (Figure 7). Streamflow response in both absolute (Figure 7) and relative (data not shown) terms increased log-linearly, from treated basins with deciduous forests that were 12 to 56 years younger than their control basins, to treated basins with conifer forests 90 to 460 years younger than their control basins. Changes in annual streamflow, in streamflow during the warm, moist season, and in the snowmelt period were significantly positively related to forest age, in both the 1 to 5- and 15 to 25- yr periods after forest removal

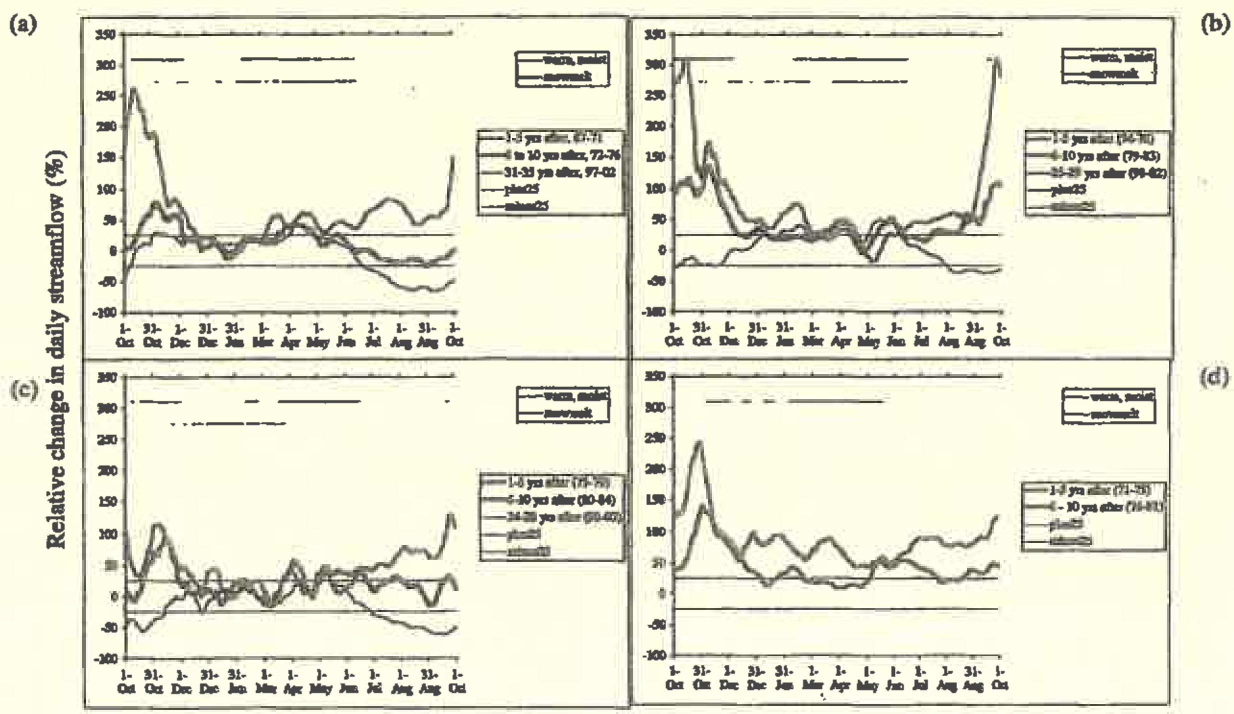

Figure 5. Relative (%) change in daily streamflow (mm) by day of water year (1 October–30 September) for 5-year periods after forest removal at fourteen treated/control basin pairs. See Figure 4 for basin names, forest types, and ages.

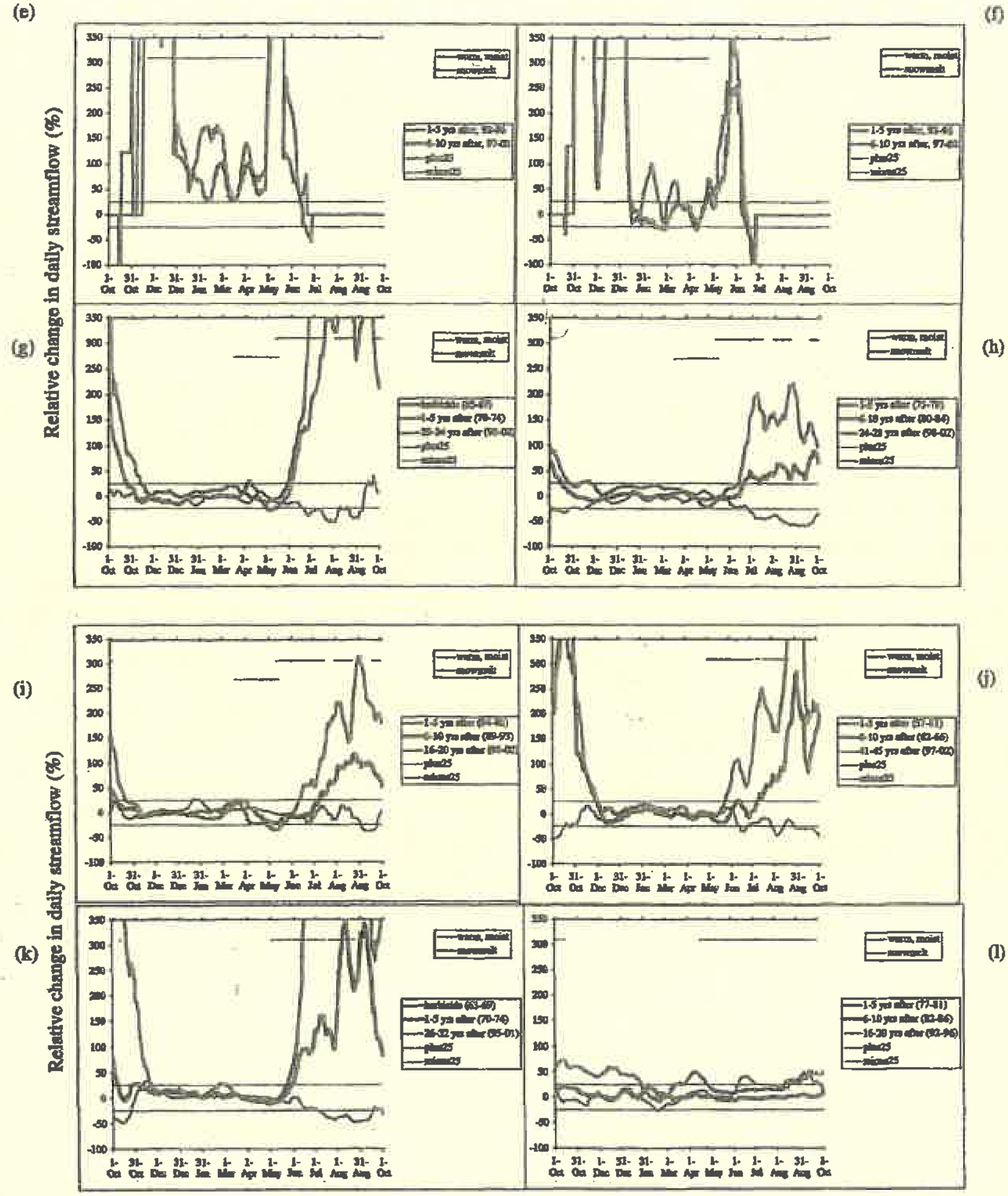

Figure 5. (continued)

(Figure 7). Fitted relationships explained from 45 to 92% of variation in absolute changes (Figure 7) and from 37 to 65% of variation in percent changes in streamflow (data not shown). Even when the "conifer-seasonal snow" points in Figure 7 were removed, six of eight regressions were still significant, with r^2 values ranging from 0.40 to 0.81. Change in streamflow during the cold season was not related to forest age in the 1 to 5-yr period, but was related to forest age in the 15 to 25-yr period after forest removal (Figures 7g and 7h).

6. Discussion

[30] Streamflow response to experimental forest removal and regrowth in fourteen treated/control basin pairs in the Pacific Northwest and eastern United States indicates that

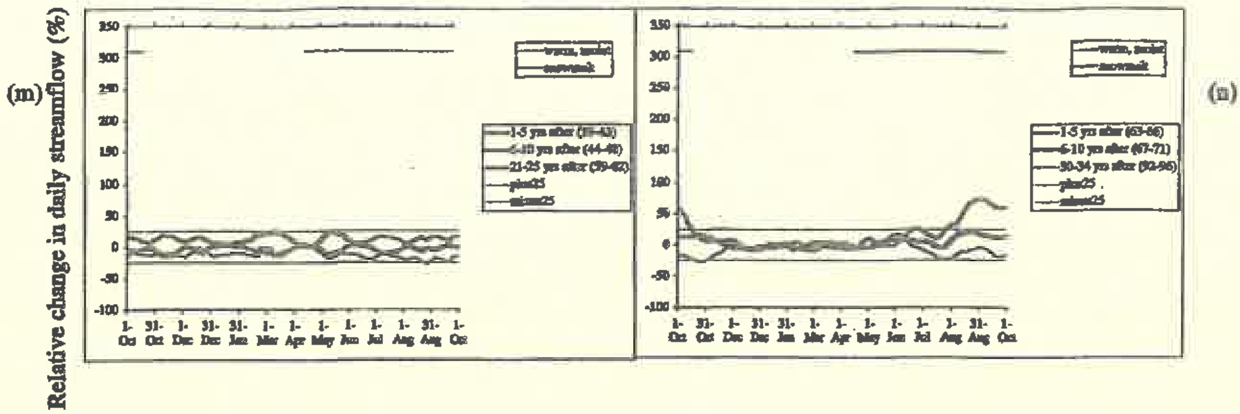

Figure 5. (continued)

Table 6. Relative Streamflow Changes in Warm Seasons After Forest Removal and During Forest Regrowth at Fourteen Pairs of Small Experimental Basins in Pacific Northwest Conifer and Eastern Deciduous Forests, USA[a]

Forest Type/Basin Pair	Treatment	Years After Forest Removal: 1 to 5	6 to 10	11 to 15	16 to 20	21 to 25	26 to 30	31 to 35	36 to 40	41 to 45
Conifer Forests										
Andrews 1/2										
Change (%)	110	60	−7	−22	−7	−5	−12	−48		
Odds ratio	61^d	53^d	0.1^d	1	2	0.3^b	1	23^d		
Andrews 6/8										
Change (%)		52	33	35	39	10	−13			
Odds ratio		22^b	2	1	1	0.1^c	2			
Andrews 10/2										
Change (%)		25	37	16	13	23	6			
Odds ratio		44^d	0.5	1.0	2^b	0.9	15^d			
Coyote 3/4										
Change (%)		145	67							
Odds ratio		145^d	0.02^b							
Deciduous Forests										
Hubbard Brook 2/3										
Change (%)	469	186	36	−12	15	−18	−42	3		
Odds ratio	404^d	18^d	9^d	3^b	7^d	20^d	22^d	18^d		
Hubbard Brook 4/3										
Change (%)		70	55	26	−25	−43	−42	−35		
Odds ratio		744^d	10^d	17^d	11^d	22^d	10^d	13^d		
Hubbard Brook 5/3										
Change (%)		91	61	0	−19					
Odds ratio		347^d	14^d	8^d	6^d					
Fernow 1/4										
Change (%)		100	10	11	17	22	33	22	1	−5
Odds ratio		334^d	4^c	4^c	10^d	5^b	7^d	7^d	6^d	6^d
Fernow 7/4										
Change (%)	95	38	6	−10	−3	5	−24			
Odds ratio	351^d	31^d	0.7	1.4	4^c	6^d	8^d			
Coweeta 7/34										
Change (%)		21	0	−11	17					
Odds ratio		0.2^d	0.2	0.6	8^d					
Coweeta 13/14										
Change (%)		4	4	−7	−10	−16				
Odds ratio		3	0.6	1	0.2	19^b				
Coweeta 37/36										
Change (%)		28	10	9	–	−5	−8	−8		
Odds ratio		173^d	3	16^b	–	11	–	0.1		

[a]Percent change and odds ratios are shown for each basin pair and postharvest time period. Blanks, dashes, and odds ratios are defined in legend to Table 5.
[b]Chi-squared tests of independence between relative streamflow changes and the warm season were significant at $p < 0.05$.
[c]Chi-squared tests of independence between relative streamflow changes and the warm season were significant at $p < 0.001$.
[d]Chi-squared tests of independence between relative streamflow changes and the warm season were significant at $p < 0.0001$.

Table 7. Absolute Streamflow Changes in Snowmelt Periods After Forest Removal and During Forest Regrowth at Fourteen Pairs of Small Experimental Basins in Pacific Northwest Conifer and Eastern Deciduous Forests, USA[a]

		Years After Forest Removal									
Forest Type/Basin Pair	Treatment	1 to 5	6 to 10	11 to 15	16 to 20	21 to 25	26 to 30	31 to 35	36 to 40	41 to 45
Conifer Forests											
Andrews 1/2											
Change (mm)	167	170	154	153	159	139	141	103		
Odds ratio	7[b]	11[d]	5[d]	8[d]	6[d]	4[c]	8[d]	7[d]		
Andrews 6/8											
Change (mm)		139	139	180	237	171	126			
Odds ratio		4[c]	4[c]	8[d]	9[d]	6[d]	12[d]			
Andrews 10/2											
Change (mm)		6	14	21	−17	−24	−14			
Odds ratio		4[c]	11[d]	4[c]	5[d]	9[d]	6[d]			
Deciduous Forests											
Hubbard Brook 2/3											
Change (mm)		−10	−8	−27	−17	−47	−19	−17	−18	
Odds ratio		0.7	12[d]	160[d]	91[d]	185[d]	60[d]	100[d]	75[d]	
Hubbard Brook 4/3											
Change (mm)		−1	−12	−5	−25	1	−4	−13		
Odds ratio		172[d]	227[d]	–	118[d]	73[d]	40[d]	60[d]		
Hubbard Brook 5/3											
Change (mm)		−41	0	10	19					
Odds ratio		372[d]	384[d]	75[d]	40[d]					

[a]Change and odds ratios are shown for each basin pair and postharvest time period. Blanks, dashes, and odds ratios are defined in legend to Table 5.
[b]Chi-squared tests of independence between absolute streamflow changes and the snowmelt season were significant at $p < 0.05$.
[c]Chi-squared tests of independence between absolute streamflow changes and the snowmelt season were significant at $p < 0.001$.
[d]Chi-squared tests of independence between absolute streamflow changes and the snowmelt season were significant at $p < 0.0001$.

forest effects on streamflow are strongly seasonal, and depend upon the age or successional stage of the forest. The analysis involved a complete re-analysis of primary data using a novel approach to paired-basin analysis, rather than relying upon reviews or meta-analyses of published studies as in *Bosch and Hewlett* [1982] or *Robinson et al.* [2003]. Our findings may differ slightly from published values for specific sites [*Rothacher*, 1970, 1975; *Douglass and Swank*, 1972; *Harr et al.*, 1979, 1982; *Swift and Swank*, 1981; *Hornbeck et al.*, 1993, 1997; *Martin et al.*, 2000; *Lewis et al.*, 2001; *Swank et al.*, 2001] because of differences in watershed pairing, use of daily average flows, and log-transformation of data. The results are relevant to ecophysiology, global change modeling, and stream ecology as well as hydrology, and they highlight the future potential for paired basin experiments.

[31] Atmospheric stresses (i.e., temperature, vapor pressure) and soil moisture stresses imposed on individual plants [e.g., *Eagleson*, 2002] scale up to influence streamflow at the small watershed scale, producing streamflow responses to forest removal and regrowth that were concentrated during seasons when moisture and temperature are conducive to evapotranspiration. Evapotranspiration depends upon (among other things) soil moisture, net interception, and evaporation from the canopy (Figure 1). Streamflow responses were larger in absolute terms after removal of conifer compared to deciduous forests, for basins with similar mean annual precipitation, confirming the site-specific work of *Swank and Douglass* [1974]. Conifers are adapted to use water throughout the year, as long as soil moisture and temperatures are not limiting, whereas transpiration in deciduous trees is limited to periods when leaves are present. Plant-level differences between conifer and deciduous forests were accentuated at the basin scale in this study, because coniferous forests were older than deciduous forests, and evapotranspiration from deciduous understory and early successional components of the regenerating conifer stands was limited by dry summers typical of these western sites.

[32] Changes in forest canopy interactions with the snowpack over the course of succession provide a possible alternative mechanism for documented long-term changes in snowmelt runoff [*Hodgekins et al.*, 2003]. Seasonal snowpack volume, and hence the snow water equivalent available to melt in the spring, depends upon the balance of additions and losses to sublimation and melt (Figure 1). Removal of deciduous forest canopies increases the exposure of cold snowpacks to winter sunlight in climates of eastern forests, and characteristically dense regenerating stands (e.g., of pin cherry [*Marks*, 1974] may intercept more snow, enhancing sublimation and reducing snowpack volume. Therefore in the first decade after removal of deciduous forest canopies, snowmelt occurred earlier and streamflow was reduced during the snowmelt period compared to 40 to 60 yr-old forests (Figures 4g–4i). This effect was reversed after two or three decades of forest regeneration, and snowmelt occurred later, but streamflow remained reduced during the snowmelt period compared to the control. In contrast, removal of conifer forest canopies decreases interception and increases the exposure of warm snowpacks to radiative heat losses, cooling mixed rain/snow to snow, in climates of Pacific Northwest forests [*Harr*, 1981]. Moreover, sparse regenerating stands [*Halpern*, 1989; *Acker et al.*, 2002] may intercept less snow. All these factors enhance snow accumulation and increase snowpack volume [*Marks et al.*, 1998; *Storck et al.*, 2002]. Therefore in the first decade after removal of conifer forest canopies, snowmelt occurred earlier and streamflow was

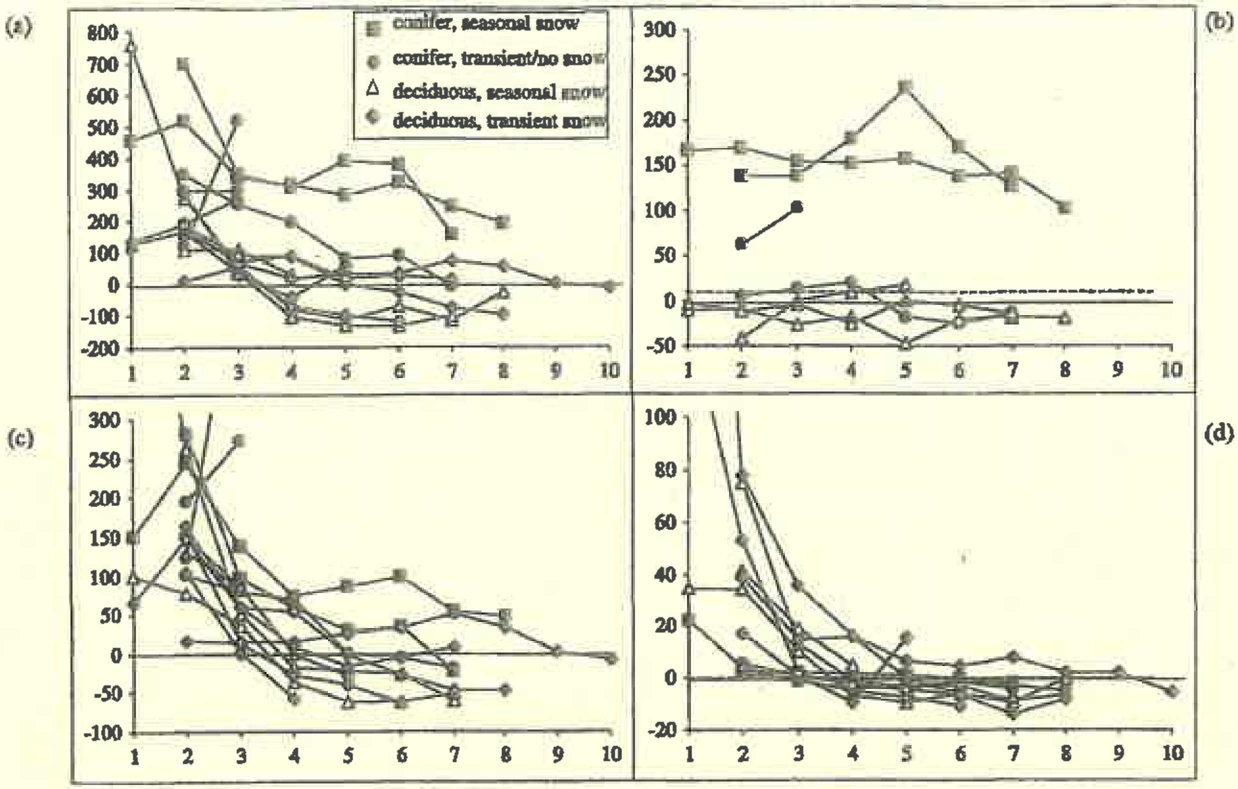

Figure 6. Effect of time since treatment (5-yr period after forest removal) on absolute changes in streamflow (mm) in fourteen treated/control basin pairs. (a) Entire water year, (b) snowmelt period, (c) warm, moist period without snow (summer for deciduous forest sites, fall for conifer forest sites), (d) August lowflow period. X axis values are 1 = treatment period, 2 = 1 to 5-years after forest removal, . . ., 10 = 41 to 45 after forest removal.

increased during the snowmelt period compared to 125 to 500 year-old forests (Figures 4a and 4b). After two or three decades of forest regeneration, snowmelt occurred later, and streamflow during the snowmelt period remained elevated, compared to the control.

[33] Streamflow variability in winter may be coupled to forest vegetation through lagged effects transmitted by soil moisture reservoirs. Lagged effects were limited to circumstances when moisture was held at high tensions, such as when soil moisture content was low or soils were very fine-textured. Soil moisture at high tensions has low hydraulic conductivity, so a "pulse" of increased or decreased soil moisture could take months to travel from the rooting zone through a small basin to the gage. Thus in deciduous sites, maximum streamflow responses in summer appeared near the middle or end of the warm period (Figures 4g–4k, 4n). In two cases (Figures 4l and 4m) the maximum streamflow response appeared several months after the end of the summer, an effect noted by earlier workers [*Swank et al.*, 1988].

[34] The strong relationships of streamflow change to two aspects of forest age (time since treatment and age of the forest at the time it was removed) support the notion that forest succession results in more efficient use of fixed moisture resources [*Eagleson*, 2002]. Forest age is a proxy for forest condition, which influences hydrologic processes. Specifically, time since treatment, and time since most recent severe disturbance are proxies for leaf area, sapwood densities, species composition, and canopy structure, which in turn are proxies for interception, evaporation, and transpiration. Thus as noted by *Hornbeck et al.* [1993, 1997] and *Swank et al.* [2001], young (10 to 30-year old) forests regenerating from disturbance were higher water users per unit leaf area than older forests (12 to 450 years older). However, based on 14 basin pairs in both conifer and deciduous forests, young forests (10 to 30 yrs old) were higher water users than old forests (70 to 450 yrs old) only in relative terms during late summer periods (August). In fact, the converse was true: removal of old (90 to 450-year old) conifer forests had a larger absolute effect on streamflow than removal of young (13 to 56-year old) deciduous forests. As forest succession proceeds over 50, 100, or 500 years, many factors (the increasing age of individual trees, changes in water use by new species succeeding in the overstory and understory, altered interception capacity, or development of a canopy epiphyte community) may increase the ability of a forest community to capture and store water. Disturbance history can help predict the ranges of streamflow responses to forest removal, but further work [e.g., *Link*, 2001] is needed to elucidate the many hydrologic mechanisms that operate in aging forests.

[35] Streamflow responses to forest removal observed in this study indicate that forest vegetation effects on streamflow variability may have consequences for stream ecology [e.g., *Poff et al.*, 1997]. In basins draining northwestern conifer forests, persistent absolute streamflow increases

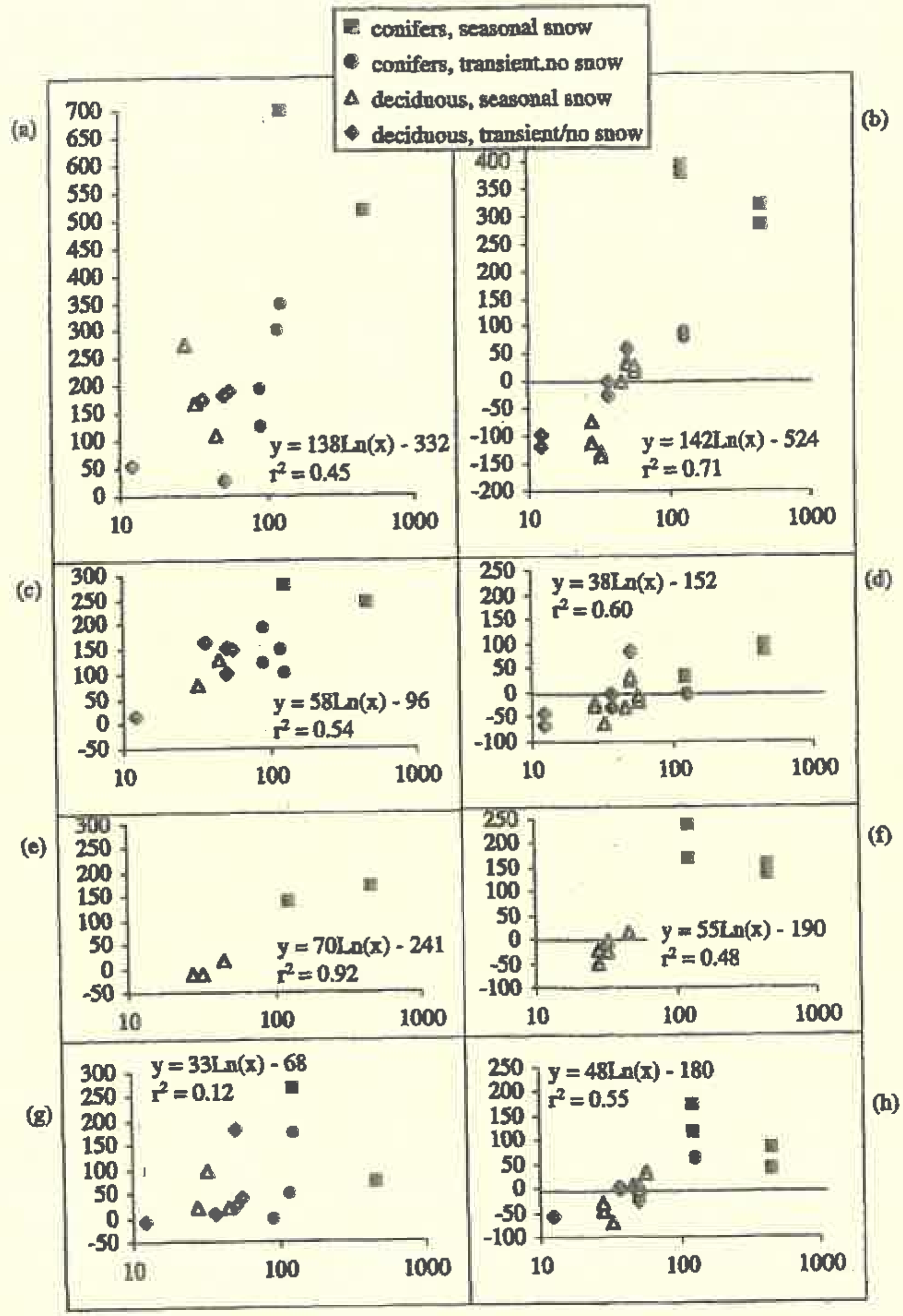

Figure 7. Effect of forest age at the time of harvest (time since most recent forest disturbance) on absolute change in water yield for various seasons and stages of succession. Entire water year: (a) 1 to 5 year and (b) 15 to 25 year periods after forest removal. Warm, moist season, fall for conifers, summer for deciduous forest: (c) 1 to 5 year and (d) 15 to 25 year periods after forest removal. Snowmelt season: (e) 1 to 5 year and (f) 15 to 25 year periods after forest removal. Cold season (winter): (g) 1 to 5 year and (h) 15 to 25 year periods after forest removal. Herbicided basin (Hubbard Brook 2) was excluded from regression for the warm, moist season, 1 to 5 year period after forest removal. Least-squares fitted log-linear models and r^2 values are shown.

during spring, combined with persistent relative summer deficits, imply that stream organisms are subjected to bigger ranges of streamflow variability in young compared to old-growth forest stands. Basins draining young eastern forests also may experience higher streamflow variability compared to older forests as a result of the combined effects of forest canopy on streamflow through changes in snow accumulation and melt, and summer water use.

[36] The methods used in this study represent a departure from prior work, and indicate the potential for continued analyses of paired-basin experiments.

[37] 1. The treated/control relationship in paired-basin experiments, rather than a black and white one, can be viewed as a function of continuous, and continuously changing, differences between basins in vegetation structure, composition, and climate. Thus multiple basins may be used as controls for a given treated basin, and the responses may be compared.

[38] 2. Paired-basin records provide the opportunity to quantify and compare streamflow responses at multiple temporal scales, including storm events, seasons, successional periods, and decadal climate change. Work is needed to examine how streamflow responses at seasonal and successional timescales, addressed in this study, interact with streamflow responses at the storm event scale [e.g., *Jones*, 2000; *Lewis et al.*, 2001], and at the scale of decadal climate change [e.g., *Greenland et al.*, 2003].

[39] 3. Small paired-basin experiments permit comparison of streamflow responses across vegetation types and treatments, climates, and basin scales. This analysis, which was restricted to <100-ha, mountainous, temperate deciduous and conifer forest basins, could be extended with additional replicates of these basin types, or records from other climates, other treatments (e.g., fire), or other vegetation types. The very high streamflow variability at basins of <20 ha may obscure some important streamflow changes, so records from larger basin scales should be included in analyses. Relevant data are available through Hydro-DB [*Baker et al.*, 2000].

[40] Prediction of streamflow from ungaged basins is a major ongiong challenge for hydrologists (see e.g., the PUB initiative, http://iahs.info). This study indicates that to some extent streamflow can be predicted from climate, forest type, and disturbance history effects on hydrologic processes. The approaches presented in this paper provide useful advances for understanding and prediction of hydrologic response.

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References

Acker, S. A., C. B. Halpern, M. E. Harmon, and C. T. Dyrness (2002), Trends in bole biomass accumulation, net primary production, and tree mortality in *Pseudotsuga menziesii* forests of contrasting age, *Tree Physiol.*, *22*, 213–217.

Baker, K. S., B. J. Benson, D. L. Henshaw, D. Blodgett, J. H. Porter, and S. G. Stafford (2000), Evolution of a multisite network information system: The LTER information management paradigm, *BioScience*, *50*(11), 963–978.

Berris, S. N., and R. D. Harr (1987), Comparative snow accumulation and melt during rainfall in forested and clear-cut plots in the western Cascades of Oregon, *Water Resour. Res.*, *23*(1), 135–142.

Beven, K. (2002), Toward an alternative blueprint for a physically based digitally simulated hydrologic response modelling system, *Hydrol. Processes*, *16*, 189–206.

Bosch, J. M., and J. D. Hewlett (1982), A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration, *J. Hydrol.*, *55*, 3–23.

Day, F. P., Jr., D. L. Phillips, and C. D. Monk (1988), Forest communities and patterns, in *Forest hydrology and ecology at Coweeta*, edited by W. T. Swank and D. A. Crossley, pp. 141–149, Springer-Verlag, New York.

Douglass, J. E., and M. D. Hoover (1988), History of Coweeta, in *Forest hydrology and ecology at Coweeta*, edited by W. T. Swank and D. A. Crossley, pp. 17–31, Springer-Verlag, New York.

Douglass, J. E., and W. T. Swank (1972), Streamflow modification through management of eastern forests, *Res. Pap. SE-94*, U.S. Dep. Agric. For. Serv. Southeastern Exp. Stn., Asheville, N. C.

Douglass, J. E., and W. T. Swank (1975), Effects of management practices on water quality and quantity: Coweeta Hydrologic Laboratory, North Carolina, *General Tech. Rep. NE-13*, U.S. Dep. Agric. For. Serv. Northeast For. Exp. Stn., Asheville, N. C.

Eagleson, P. S. (2002), Ecohydrology: Darwinian expression of vegetation form and function, Cambridge Univ. Press, New York.

Greenland, D., D. G. Goodin, and R. C. Smith (2003), Climate variability and ecosystem response at long-term ecological research sites, Oxford Univ. Press, New York.

Halpern, C. B. (1989), Early successional patterns of forest species: Interactions of life history traits and disturbance, *Ecology*, *70*, 704–720.

Harr, R. D. (1981), Some characteristics and consequences of snowmelt during rainfall in western Oregon, *J. Hydrol.*, *53*, 277–304.

Harr, R. D. (1982), Fog drip in the Bull Run municipal watershed, Oregon, *Water Resour. Bull.*, *18*(5), 785–789.

Harr, R. D., R. L. Fredriksen, and J. Rothacher (1979), Changes in streamflow following timber harvest in southwestern Oregon, *Res. Pap. PNW-249*, U.S. For. Serv. Pacific Northwest Res. Stn., Corvallis, Oreg.

Harr, R. D., A. Levno, and R. Mersereau (1982), Streamflow changes after logging 130-yr-old Douglas fir in two small watersheds, *Water Resour. Res.*, *18*(3), 637–644.

Hodgekins, G. A., R. W. Dudley, and T. G. Huntington (2003), Changes in the timing of high river flows in New England over the 20th century, *J. Hydrol.*, *278*, 244–252.

Hornbeck, J. W., M. B. Adams, E. S. Corbett, E. S. Verry, and J. A. Lynch (1993), Long-term impacts of forest treatments on water yield: A summary for northeastern USA, *J. Hydrol.*, *150*, 323–344.

Hornbeck, J. W., C. W. Martin, and C. Eagar (1997), Summary of water yield experiments at Hubbard Brook Experimental Forest, New Hampshire, *Can. J. For. Res.*, *27*, 2043–2052.

Jones, J. A. (2000), Hydrologic processes and peak discharge response to forest removal, regrowth, and roads in 10 small experimental basins, western Cascades, Oregon, *Water Resour. Res.*, *36*(9), 2621–2642.

Jones, J. A., and G. E. Grant (1996), Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon, *Water Resour. Res.*, *32*(4), 959–974.

Jones, J. A., and F. J. Swanson (2001), Hydrologic inferences from comparisons among small basin experiments, *Hydrol. Processes*, *15*, 2363–2366.

Lewis, J., S. R. Mori, E. T. Keppeler, and R. R. Ziemer (2001), Impacts of logging on storm peak flows, flow volumes, and suspended sediment loads in Caspar Creek, California, in *Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas*, *Water Sci. and Appl. Ser.*, vol. 2, edited by M. S. Wigmosta and S. J. Burges, pp 85–125, AGU, Washington, D. C.

Link, T. E. (2001), The water and energy dynamics of an old-growth seasonal temperate rainforest, Ph.D. dissertation, Environ. Sci. Graduate Program, Oreg. State Univ., Corvallis.

Marks, D., J. Kimball, D. Tingey, and T. Link (1998), The sensitivity of snowmelt processes to climate conditions and forest cover during rain-on-snow: A case study of the 1996 Pacific Northwest flood, *Hydrol. Processes*, *12*, 1569–1587.

Marks, P. L. (1974), The role of pin cherry in the maintenance of stability in northern hardwood ecosystems, *Ecol. Monogr.*, *44*, 73–88.

Martin, C. W., J. W. Hornbeck, G. E. Likens, and D. C. Buso (2000), Impacts of intensive harvesting on hydrology and nutrient dynamics of northern hardwood forests, *Can. J. For. Res.*, *57*(Suppl. 2), 19–29.

Perkins, R. M. (1997), Climate and physiographic controls on peakflow generation in the western Cascades, Oregon, Ph.D. dissertation, Dept. of Forest Science, Oreg. State Univ., Corvallis.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg (1997), The natural flow regime: A paradigm for river conservation and restoration, *BioScience*, *47*, 769–784.

Post, D. A., and J. A. Jones (2001), Hydrologic regimes at four long-term ecological research sites in New Hampshire, North Carolina, Oregon, and Puerto Rico, *Adv. Water Resour.*, *24*, 1195–1210.

Post, D. A., G. E. Grant, and J. A. Jones (1998), Ecological hydrology: Expanding opportunities in hydrologic sciences, *Eos Trans. AGU*, *79*(43), 517.

Ramsay, F. L., and D. W. Schaefer (1996), *The Statistical Sleuth*, 742 pp., Duxbury, Boston, Mass.

Robinson, M., et al. (2003), Studies of the impact of forests on peak flows and baseflows: A European perspective, *For. Ecol. Manage.*, *1186*, 85–97.

Rothacher, J. (1970), Increases in water yield following clear-cut logging in the Pacific Northwest, *Water Resour. Res.*, *6*(2), 653–658.

Rothacher, J. (1975), Regimes of streamflow and their modification by logging, in *Forest Land Uses and Environment*, edited by J. T. Krygier and J. D. Hall, pp. 40–54, Oreg. State Univ. Press, Corvallis.

Rothacher, J., C. T. Dyrness, and R. L. Fredriksen (1967), Hydrologic and related characteristics of three small watersheds in the Oregon Cascades, 54 pp., U. S. Dep. Agric. For. Serv., Pacific Northwest For. and Range Exp. Stn., Ashville, N. C.

Schwarz, P. A., T. J. Fahey, C. W. Martin, T. G. Siccama, and A. Bailey (2001), Structure and composition of three northern hardwood-conifer forests with different disturbance histories, *For. Ecol. Manage.*, *144*, 201–212.

Shafer, S. L., P. J. Bartlein, and R. S. Thompson (2001), Potential changes in the distributions of Western North America tree and shrub taxa under future climate scenarios, *Ecosystems*, *4*, 200–215.

Storck, P., D. P. Lettenmaier, and S. M. Bolton (2002), Measurement of snow interception and canopy effects on snow accumulation and melt in a mountainous maritime climate, Oregon, United States, *Water Resour. Res.*, *38*(11), 1223, doi:10.1029/2002WR001281.

Swank, W. T., and J. E. Douglass (1974), Streamflow greatly reduced by converting deciduous hardwood stands to white pine, *Science*, *185*, 857–859.

Swank, W. T., L. W. Swift Jr., and J. E. Douglass (1988), Streamflow changes associated with forest cutting, species conversions, and natural disturbances, in *Forest Hydrology and Ecology at Coweeta*, edited by W. T. Swank and D. A. Crossley, pp. 297–312, Springer-Verlag, New York.

Swank, W. T., J. M. Vose, and K. J. Elliott (2001), Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment, *For. Ecol. Manage.*, *143*, 163–178.

Swift, L. W., and W. T. Swank (1981), Long-term responses of streamflow following clearcutting and regrowth, *Hydrol. Sci. Bull.*, *26*, 245–256.

Weisberg, P. J., and F. J. Swanson (2003), Regional synchroneity in wildfire regimes of western Oregon and Washington, USA, *For. Ecol. Manage.*, *172*, 17–28.

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(4)

AN ABSTRACT OF THE THESIS OF

Timothy D. Perry for the degree of Master of Science in Geography presented

on December 7, 2007.

Title: Do Vigorous Young Forests Reduce Streamflow? Results from up to 54 Years of Streamflow Records in Eight Paired-watershed Experiments in the H. J. Andrews and South Umpqua Experimental Forests.

Abstract approved:

Julia A. Jones

This study quantified the magnitude and timing of summer streamflow deficits in paired-watershed experiments in the Cascade Range of Oregon where mature and old-growth conifer forests were subjected to clearcutting, patch cutting, and overstory thinning treatments in the 1960s and 1970s. Hydrologic effects of clearcutting, small-patch cutting, and overstory thinning in the mixed conifer/brush zone were studied (1 watershed (WS) each) in the Coyote Creek WS of the South Umpqua Experimental Forest at 42° 1′ 15″N and 122° 43′ 30″W. Hydrologic effects of clear cutting (3 WS), shelterwood cutting (1 WS), patch cutting (1 WS), and young forest thinning

(1 WS) were examined in the Tsuga heterophylla zone at the H. J. Andrews experimental forest at 44° 14′ 0″N and 122° 11′ 0″ W. Climate of both sites is marine west coast with winter precipitation and dry summers, producing minimum streamflows in August and September. Changes in flow frequency distributions were detected by counting days below streamflow thresholds where the thresholds were established using percentiles from pre-cutting streamflow records. Changes in relative streamflow were established by the station pair method. Summer streamflow deficits were largest and most persistent in 35 to 50-year-old forest plantations created from clearcutting and shelterwood cutting in the 1960s and 1970s. Summer streamflow deficits were smallest and most ephemeral in a stand that experienced 50% overstory thinning in 1971. Summer streamflow deficits of intermediate size and persistence developed in watersheds in which 25 to 30% of the area had been patchcut in the 1960s or 1970s. A sparse (12%) precommercial thin of a 27-year-old stand exhibiting summer streamflow deficits had comparatively little effect on streamflow deficits. Streamflow deficits emerged as early as March or April and persisted into October and November in the warmer, drier site in southern Oregon (Coyote Creek), whereas summer streamflow deficits were restricted to July through September in the cooler, wetter Andrews Forest. These findings are

consistent with previous studies demonstrating (1) increases in water use in certain conifer species relative to others (e.g. Douglas-fir versus pine); (2) higher water use in young (i.e., 10 to 50-yr-old) compared to old (100 to 250-yr-old) stands of many tree species; and (3) decreased interception capacity of young relative to old forest stands associated with loss of canopy epiphytes. Results appear to be robust, despite gaps in data availability, uncertainties associated with changes in stream gauging, streamflow trends over time in control watersheds, and multi-decadal fluctuations in regional climate over the study period. These findings support the notion that variable-intensity logging prescriptions over small areas to approximate natural forest structure may have the least effect on summer streamflows. However, more research, preferably new paired watershed experiments, is needed to quantify the magnitude and duration of summer streamflow effects from various levels of overstory and understory thinning treatments.

(S)

Summer streamflow deficits from regenerating Douglas-fir forest in the Pacific Northwest, USA

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ABSTRACT

Despite controversy about effects of plantation forestry on streamflow, streamflow response to forest plantations over multiple decades is not well understood. Analysis of 60-yr records of daily streamflow from eight paired-basin experiments in the Pacific Northwest of the United States (Oregon) revealed that conversion of old-growth forest to Douglas-fir plantations had a major effect on summer streamflow. Average daily streamflow in summer (June through September) in basins with 34 to 43-yr-old plantations of Douglas-fir was 50% lower than streamflow from reference basins with 150 to 500-yr-old forests dominated by Douglas-fir, western hemlock, and other conifers. Study plantations are comparable in terms of age class, treatments, and growth rates to managed forests in the region. Young Douglas-fir trees, which have higher sapwood area, higher sapflow per unit of sapwood area, higher concentration of leaf area in the upper canopy, and less ability to limit transpiration, appear to have higher rates of evapotranspiration than old trees of conifer species, especially during dry summers. Reduced summer streamflow in headwater basins with forest plantations may limit aquatic habitat and exacerbate stream warming, and it may also alter water yield and timing in much larger basins. Legacies of past forest management or extensive natural disturbances may be confounded with effects of climate change on streamflow in large river basins. Continued research is needed using long-term paired-basin studies and process studies to determine the effects of forest management on streamflow deficits in a variety of forest types and forest management systems.

Keywords: stationarity, succession, climate change, native forests, plantations, water scarcity

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1. INTRODUCTION

Widespread evidence that streamflow is declining in major rivers in the US and globally raises concerns about water scarcity (Adam *et al.*, 2009; Dai *et al.*, 2009; Luce and Holden, 2009; Vorosmarty *et al.*, 2000). Climate change and variability are implicated as causes of many streamflow trends (Lins and Slack, 1999, 2005; McCabe and Wolock, 2002; Mote *et al.*, 2003; Hodgkins *et al.*, 2003, 2005; Stewart *et al.*, 2004, 2005; Nolin and Daly, 2006; Hamlet and Lettenmaier, 2007; Barnett *et al.*, 2008; Jefferson *et al.*, 2008; Lara *et al.*, 2008; Dai *et al.*, 2009; Kennedy *et al.*, 2009; Jones, 2011). However, large-scale plantation forestry, often using non-native tree species, is expanding in much of the temperate zone on Earth, despite widespread evidence that intensive forestry reduces water yield (Cornish and Vertessy, 2001; Andreassian, 2004; Brown *et al.*, 2005, Farley *et al.*, 2005; Sun *et al.*, 2006; Little *et al.*, 2009). Water yield reductions are greater in older plantations, during dry seasons and in arid regions (Andreassian, 2004; Brown *et al.*, 2005; Farley *et al.*, 2005; Sun *et al.*, 2006). Yet, downstream effects of forestry are debated (van dijk and Keenan, 2007).

Despite general studies of water partitioning in forested basins (e.g., Budyko, 1974, Zhang *et al.*, 2001, Jones *et al.*, 2012), it is unclear how streamflow varies during forest succession, relative to tree species, age, or growth rates in native forest and forest plantations (Creed *et al.*, 2014). In the Pacific Northwest of the US, forest plantations have reduced summer streamflow relative to mature and old-growth forest (Hicks *et al.*, 1991; Jones and Post, 2004). However, the magnitude, duration, causes, and consequences of summer water deficits associated with forest plantations are not well understood.

In the Pacific Northwest, large areas of old-growth forest have been converted to forest plantations. We examined how changes in forest structure and composition have affected streamflow using multiple paired-basin experiments in western and southwestern Oregon, where regenerating forests are currently aged 40 to 50 years, and reference forests are aged 150 to 500 years. Many studies have reported on these experiments, including vegetation ecology (e.g., Marshall and Waring, 1984; Halpern, 1989; Halpern and Franklin, 1990; Halpern and Spies, 1995; Lutz and Halpern, 2006; Halpern and Lutz, 2013) and hydrology (e.g., Rothacher, 1970; Harr *et al.*, 1979; Harr and McCorison 1979; Harr *et al.*, 1982; Hicks *et al.*, 1991; Jones and Grant, 1996, Jones, 2000; Jones and Post, 2004, Perkins and Jones, 2008; Jones and Perkins, 2010; Jennings and Jones, 2015). We asked:

1. How has daily streamflow changed over the past half century in reference basins with 150- to 500-yr-old forest?
2. What are the trends in daily streamflow over 40 to 50-year periods, from basins with regenerating forests compared to reference basins?
3. How are changes in summer streamflow related to forest structure and composition in mature and old-growth forests vs. forest plantations?

2. STUDY SITE

The study examined streamflow changes in eight pairs of treated/reference basins in five paired-basin studies. Five of the basin pairs (eight basins) were located in the H.J. Andrews Experimental Forest (122° 15' W, 44° 12' N) in the Willamette National Forest. Three basin pairs (4 basins) were located at Coyote Creek in the South Umpqua Experimental Forest (122° 42' W, 43° 13' N) in the Umpqua National Forest (Table 1, Figure 1). Basins are identified as Andrews 1, 2, etc. = AND 1, 2, etc.; Coyote 1, 2, etc. = COY 1, 2, etc. (Table 1).

The geology of the study basins is composed of highly weathered Oligocene tuffs and breccias that are prone to mass movements. The upper elevation portion of the Andrews Forest (above ~800 m, AND 6, AND 7, AND 8) is underlain by Miocene andesitic basalt lava flows (Dyrness, 1967; Swanson and James, 1975; Swanson and Swanston, 1977). Soils are loamy, well-drained, and moderately to highly permeable, with considerable variation in depth and rock content (Rothacher *et al.*, 1969; Dyrness, 1969; Dyrness and Hawk, 1972).

The Andrews Forest ranges from 430 to 1600 m elevation; study basins range from 430 to 1100 m elevation (Table 1). Area-averaged slope gradients are >60% at low elevation (AND 1, AND 2, AND 3, AND 9, AND 10) and 30% at high elevation (AND 6, AND 7, AND 8). Mean daily temperature ranges from 2°C (December) to 20°C (July) at 430 m and from 1°C (December) to 17°C (July) at 1300 m. Mean annual precipitation is 2300 mm, >75% of precipitation falls between November and April, and actual evapotranspiration (AET) averages 45% of precipitation. The South Umpqua Experimental Forest (Coyote Creek basins) ranges from 730 to 1065 m elevation. Most slope gradients are <40% (Arthur 2007). Mean daily temperature (at USHCN station OR356907, 756 m elevation, 30 km SE of Coyote Creek) ranges from 3 °C (December) to 20 °C (July). Mean annual precipitation (at OR356907) is 1027 mm, >80% of precipitation falls between November and April, and AET averages 45% of precipitation.

Study basins are located along a gradient of seasonal snow depth and duration (Harr, 1981, 1986). At high elevation (> 800 m, AND 6, AND 7, and AND 8), average snowpack water equivalent (SWE) on April 30 exceeds 700 mm (30% of annual precipitation), and snow may persist for six months, whereas at low elevation (<700 m, AND 9, AND 10), snow rarely persists more than 1–2 weeks and usually melts within 1–2 days; peak SWE is ~2% of precipitation (Harr *et al.*, 1979; Harr and McCorison, 1979; Harr *et al.*, 1982; Perkins and Jones, 2008). Snow at the South Umpqua Experimental Forest (Coyote Creek) usually melts within 1–2 weeks.

Vegetation at the Andrews Forest is Douglas-fir/western hemlock forest. Mature and old-growth forest regenerated after wildfires in the early 1500s and mid-1800s (Weisberg and Swanson 2003, Tepley 2010, Tepley *et al.*, 2013). Overstory canopy cover is 70 to 80% and leaf area index is >8 (Dyrness and Hawk, 1972; Marshall and Waring, 1986; Lutz and Halpern, 2006). Vegetation at the South Umpqua Experimental Forest is mixed conifer (Douglas-fir, white fir, incense cedar, sugar pine), and overstory canopy cover is 70 to 80% (Anderson *et al.*, 2013).

At the Andrews Forest the first paired-basin experiment began in 1952 (AND 1, 2, 3); a second paired basin experiment began in 1963 (AND 6, 7, 8) and a third paired-basin experiment began in 1968 (AND 9, 10), with continuous records except at AND 7 (Table 1). Pre-treatment periods exceeded seven years in all cases and were ten years for AND 1/2, AND 6/8, and AND 7/8. Streamflow instrumentation changed in some basins over the period of record (Table 1). Because of the timing of instrumentation changes at AND 9/10, AND 2 is used as the reference basin for AND 10 (see supplemental material). At the South Umpqua Experimental Forest, the Coyote Creek paired-basin experiment began in 1963 (Table 1). The pre-treatment period was seven years. Despite a break in the record from 1981 to 2000, streamflow instrumentation is unchanged (M. Jones, personal communication).

3. METHODS

This study examined changes in daily average streamflow and its relationship to climate and forest structure and species composition in paired basins. Climate, vegetation, and streamflow have been measured for multiple decades at the Andrews Forest and Coyote Creek (see supplemental materials). Tree-level vegetation data were used to calculate basal area for all species, proportions of basal area for major species, and size class distributions.

Daily streamflow data for the period of record were used to calculate the change in streamflow by day of water year utilizing the method developed by Jones and Post (2004). The ratio *R* of daily streamflow between the treated basin *T* and reference (control) basin *C* for year *y* and day *d* was calculated following Eberhardt and Thomas (1991) as:

$$R_{yd} = \ln(T_{yd} / C_{yd}) \quad (1)$$

The mean value of this ratio M for all the years *y* in a given period *p* was:

$$M_{pd} = \text{Average } (R_{yd}) \text{ for all "y" in "p"} \quad (2)$$

The percent difference P_{pd} between the treated:reference ratio of streamflow on day *d* in the pre- and post-treatment period *p* compared to M_{pd} in the pre-treatment period 0 (M_{0d}), was:

$$P_{pd} = 100*(e^{(M_{pd} - M_{0d})} - 1) \quad (3)$$

The 15-day smoothed percent change in daily streamflow, *S*, was:

$$S_{pd} = \sum(P_{pD}*E_{pD}) / \sum(E_{pD}) \text{ over } D = d\text{-}7, d\text{-}6, \ldots, d, \ldots, d + 6, , d{+}7 \quad (4)$$

The smoothed daily percent difference S_{pd} was averaged for 5-year post-treatment periods and plotted as a function of day of the water year. S_{pd} also was summed by month and plotted as a function of time (year). Percent changes in daily streamflow were calculated for eight treated/reference basin pairs: COY 1/4, COY 2/4, COY 3/4, AND 1/2, AND 3/2, AND 6/8, AND 7/8, AND 10/2. The significance of percent changes was assessed based on comparison with the 15-day smoothed values of the pre-treatment standard error of P_{pd}.

A daily soil water balance was created for AND 2 based on mean daily values of precipitation and discharge, daily evapotranspiration estimated from S_{pd} (Jones and Post, 2004) and mean daily snow water equivalent modeled in Perkins and Jones (2008). In addition, long-term trends in streamflow were calculated for each day of the water year from the beginning of the record to 1996, for AND 2, 8, and 9, following Hatcher and Jones (2013) (see supplemental materials).

Flow percentiles were calculated for each gage record, and the numbers of days of flow below each percentile were tallied by water year. The difference in numbers of days below selected percentiles between the treated and reference basin for 1995 to 2005 was calculated and compared to summer discharge at the reference basin for 100% treated/reference pairs.

4. RESULTS

The structure and composition of native mature and old-growth forest in reference basins varied, reflecting wildfire history, but was stable over the study period. Basal area ranged from 66 to 89 m^2/ha depending on the basin and the year (Table 2). Douglas-fir (*Pseudotsuga menziesii*) was the dominant species, representing 55 to more than 90% of basal area, with varying amounts of western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*) in AND 2 and AND 8, and California incense cedar (*Calocedrus* *decurrens*) and white fir (*Abies concolor*) in COY 4 (Table 2). Trees in AND 2 (N-facing) and AND 8 (upper-elevation) were very large, with weighted mean stem diameter of roughly 0.66 m. In contrast, trees were smaller on the low-elevation, SW-facing, relatively hot, dry slopes of AND 9 and the mid-elevation COY 4 in southwest Oregon, with mean diameter of just over 0.3 m (Table 2). Stem density ranged from 87 stems/ha at the N-facing AND 2 to over 400 stems/ha at the SW-facing AND 9. Over a 25-year period, stem density and basal area were stable in AND 2, although there was a slight net loss of Douglas-fir and a gain of western hemlock (Table 2). The size-class distributions of Douglas-fir reveal moderate-severity historical fire in AND 2 and moderate to high-severity fire AND 8 in the mid 1800s, which produced cohorts of regenerating Douglas-fir (Figure 2).

Basal area and growth rates in the 34 to 43-yr-old plantations in the treated basins are at the lower end of those reported for managed plantations in the region (Figure 3). Basal area at the most recent measurement period (2007 to 2010) ranged from 27 to 35 m^2/ha, or between one-third and one-half of the basal area in the corresponding reference basin (Table 2). Douglas-fir, which was planted in the treated basins, was the dominant species, representing more than 80% of basal area. Stem density was five to ten times higher in plantations than matched reference basins, and ranged from 533 to more than 1700 stems/ha (Table 2). Mean diameters in plantations were one-third to one-fifth of those in corresponding reference basins, except for COY 1, where the large mean stem diameter (31 cm) reflects the retention of 50% of the overstory from the shelterwood harvest (Table 1, Table 2). Trees were smallest in AND 7 (shelterwood harvest, plantation aged 34 yrs) and largest in 100% clearcut and burned basins AND 1 (plantation, aged 40 yrs) and COY 4 (plantation, aged 35 yrs). AND 10, which was clearcut but not burned, had a very high number of small stems (plantation, aged 35 yrs) (Table 1, Table 2, Figure 2). Adjusting for age, rates of basal area growth were similar in all the 100% clearcut basins. The unburned basin (AND 10) and the shelterwood harvest basin (AND 7) had slightly lower rates of growth in the third decade after harvest (AND 10) and a pre-commercial thin (12% basal area removal) at year 28 in AND 7, but rates were similar by 35 years (Figure 3).

The daily soil water balance for the reference basin (AND 2, Figure 4) reveals extremely low rates of evapotranspiration and soil moisture in old-growth forests during the summer (July through September). Evapotranspiration is limited by low temperature in winter, and low soil moisture in summer.

Daily streamflow has not changed in reference basins (Figure 5). Runoff declined slightly during the periods of snowmelt, but these minor changes were significant only at AND 2 (Figure 5). Summer streamflow did not change over time.

Conversion of old-growth forest to Douglas-fir plantations, which reached 34 to 43 years of age by the end of the record analyzed here, had a major effect on summer streamflow. By the mid 1990s, average daily flow in summer (June through September) in basins with plantation forests had declined by roughly 50% relative to the reference basins with 150 to 500-yr-old forests (Figure 6 a). When plotted by time since harvest, summer streamflow deficits appeared when plantation forests reached fifteen years of age (Figure 6 b). The trend of declining summer streamflow was temporarily reversed in the late 1980s, especially at AND 1/2 and AND 6/8, after a severe freezing event in November of 1986. A pre-commercial thin (12% basal area) in AND 7 in 2001 did not slow the decline of summer streamflow.

When examined by day of year, forest harvest produced large streamflow increases from June through December in the first ten years after harvest (Figure 7). Initial summer streamflow surpluses were lowest, and disappeared most quickly, in 50% thinned ("shelterwood") basins (AND 7, COY 1), and they were highest at the 100% clearcut basins (AND 1, 6, 10, COY 3) (Figure 7). Conversion of mature and old forest to young plantations produced streamflow surpluses in winter and spring of 25 to 50%, which persisted virtually unchanged to the present in the Andrews Forest, but not at the drier, more southerly Coyote Creek (Figure 7).

By 20 to 25 years after 100% clearcutting, summer streamflow was lower in all plantation forests compared to reference basins (Figure 7 a to e) and also in one 25% patch cut basin (Figure 7 g). In 100% clearcut basins, summer streamflow deficits began by early July, and persisted until early October (AND 1, AND 7, Figure 7 a,c), to the end of November (AND 6, AND 10, Figure 7 b,d), or to the end of December (COY 3, Figure 7 e). Deficits were largest in August and September, when streamflow from forest plantations was 50% lower than from reference basins. Summer deficits did not emerge over time in treatments involving shelterwood (50% thinned, COY 1) and very small gaps (0.6 to 1.3-ha patch cuts, COY 2) (Figure 7 f,h). Relative to 50% thinning (shelterwood) and very small gaps, intermediate-sized gaps (8-ha patch cuts, AND 3) produced larger initial summer surpluses and persistent summer deficits. The largest gaps (20 to 100-ha clearcuts) produced the largest summer surpluses and the largest, persistent summer deficits, which extended into the fall season (Figure 7 a-d). Thinning of young forest (AND 7) did not counteract summer streamflow deficits.

Summer streamflow deficits occurred during the period of minimum flow, when soil moisture is most limiting (Figure 4, 7). The duration of summer streamflow deficits (defined as difference in the number of days below the 1st percentile in basins with plantations vs. reference basins) was greater during dry compared to wet summers, at low compared to high elevation, and at the more southerly Coyote Creek compared to the Andrews Forest (Figure 8). Forest plantations that were aged 25 to 35 years in 1995 to 2005 had as many as 100 more days with flow below the 1st percentile compared to the reference basin (Figure 8). Within a basin pair, the number of days of flow below the 1st percentile increased in dry relative to wet summers (Figure 8).

5. DISCUSSION

This study showed that, relative to mature and old-growth forest dominated by Douglas-fir and western hemlock or mixed conifers, forest plantations of native Douglas-fir produced summer streamflow deficits within fifteen years of plantation establishment, and these deficits have persisted and intensified in 50-yr-old forest stands. Forest stands in the study basins, which are on public forest land, are representative of managed (including thinned) forest stands on private land in the region, in terms of basal area over time (Figure 3), age (10 to 50 years), clearcut size (20 ha), and average rotation age (50 years) (Lutz and Halpern, 2006; Briggs 2007). There are no significant trends in annual or summer precipitation (Abatzoglou *et al.*, 2014) or streamflow at reference basins over the study period. This finding has profound implications for understanding of the effects of land cover change, climate change, and forest management on water yield and timing in forest landscapes.

The size of canopy opening explained the magnitude and duration of initial summer streamflow surpluses and subsequent streamflow deficits, consistent with work on soil moisture dynamics of canopy gaps. In 1990, Gray *et al.* (2002) created experimental gaps in mature and old-growth forests in Oregon and Washington, including neighboring sites to the study basins, with gap sizes of 40 to 2000 m^2 (tree height to gap size ratios of 0.2 to 1.0). The smallest gaps dried out faster during the summer than the largest gaps, with the highest moisture levels in the medium-sized gaps, which had less direct radiation and less vigorous vegetation than the largest gaps. In late summer (September) volumetric soil moisture declined to 15% in references, 18% in small gaps, and 22% in each of the first three years after gap creation (Gray *et al.*, 2002). Together, the paired-basin and experimental gap results indicate that even-aged plantations in 8-ha or larger clearcuts are likely to develop summer streamflow deficits, and these deficits are unlikely to be substantially mitigated by dispersed thinning or small gap creation.

Relatively high rates of summer evapotranspiration by young (25 to 45-yr-old) Douglas-fir plantations relative to mature and old-growth forests apparently caused reduced summer streamflow in treated basins. Young Douglas-fir trees (in AND 1) had higher sapflow per unit sapwood area and greater sapwood area compared to old Douglas-fir trees (in AND 2) (Moore *et al.* (2004). In summer, young Douglas-fir trees have higher rates of transpiration (sapflow) compared to old Douglas-fir trees, because their fast growth requires high sapwood area, and because their needles appear to exercise less stomatal control when vapor pressure deficits are high. Leaf area is concentrated in a relatively narrow height range in the forest canopy of a forest plantation, whereas leaf area is distributed over a wide range of heights in a mature or old-growth conifer forest. In summer, these factors appear to contribute to higher daily transpiration rates under young conifers relative to mature or older conifers, producing pronounced reductions in streamflow during the afternoons of hot dry days (Bond *et al.*, 2002). At sunset, transpiration ceases, and streamflow recovers. Hence, daily transpiration produces large diel variations in streamflow in AND 1 (plantation) relative to AND 2 (reference). Other factors, such as differences in tree species composition (Table 2), the presence of a hyporheic zone, or deciduous trees in the riparian zone of AND 1, may also contribute to differences in streamflow between these basins (Bond *et al.*, 2002; Moore *et al.*, 2004; Wondzell *et al.*, 2007).

Reduced summer streamflow has potentially significant effects on aquatic ecosystems. Summer streamflow deficits in headwater basins may be particularly detrimental to anadromous fish including steelhead and salmon, by limiting habitat, exacerbating stream temperature warming, and potentially causing large-scale dieoffs (Hicks *et al.*, 1991; Arismendi *et al.*, 2012, 2013, Isaak *et al.*, 2012). Summer streamflow deficits may also exacerbate tradeoffs in water use between in-stream flows, irrigation, and municipal water use.

Reductions in summer streamflow in headwater basins with forest plantations may affect water yield in much larger basins. Much of the Pacific Northwest forest has experienced conversion of mature and old-growth forests to Douglas-fir plantations over the past century. Climate warming and associated loss of snowpack is expected to reduce summer streamflow in the region (e.g., Littell *et al.*, 2010). Declining summer streamflows in the Columbia River basin may be attributed to climate change (Chang *et al.*, 2012, 2013; Hatcher and Jones, 2013), but these declines may also be the result of cumulative forest change due to plantation establishment, fire suppression (Perry *et al.*, 2003), and forest succession after wildfire and insect outbreaks, which kill old trees and promote growth of young forests (e.g., Biederman *et al.*, 2015).

Air temperature has warmed slightly in the Pacific Northwest (0.6 to 0.8°C from 1901 to 2012 [Abatzoglou *et al.*, 2014]), but water yields from mature and old-growth forests in reference basins have not changed over time. In the reference basins used in this study, we observed small changes in biomass and shifts in species dominance, consistent with changes expected as part of forest succession in mature and old-growth forests, but we did not observe large-scale mortality documented by van Mantgem *et al.* (2009).

This study demonstrates that plantations of native tree species produced summer streamflow deficits relative to mature and old-growth forest, consistent with prior studies in the US Pacific Northwest (Jones and Post, 2004) and in mixed-deciduous forests in the eastern US (Hornbeck *et al.*, 1997). Research is needed to compare these effects to declining water yield from plantations of fast-growing non-native species in the southern hemisphere (Little *et al.*, 2009, 2014; Scott 2005; Farley *et al.*, 2005). Despite summer streamflow deficits, young forest plantations in the Andrews Forest yield more water in winter, contributing to increased flooding (Harr and McCorison, 1979; Jones and Grant, 1996; Beschta *et al.*, 2000; Jones, 2000; Jones and Perkins, 2010).

6. CONCLUSIONS

Paired basin experiments are central to advancing long-term, integrated forest hydrology. Over the past half-century, many key paired-basin experiments (e.g., at US Forest Service Experimental Forests and LTER sites such as Coweeta, Hubbard Brook, and Andrews, as well as others) have evolved into headwater ecosystem studies, with detailed information about hydrology, climate, vegetation, biogeochemistry, and sediment export. These studies provide rigorous causal inferences about effects of changing vegetation on streamflow at successional time scales (multiple decades) of interest in basic ecology, applied forestry and conservation. They permit researchers to distinguish forest management from climate change effects on streamflow. Paired-basin experiments are place-based science, integrate multiple disciplines of science and policy, and can dispel assumptions and conjectures such as equilibrium, common in hydrological modeling studies.

Long-term paired-basin studies extending over six decades revealed that conversion of mature and old-growth conifer forests to plantations of native Douglas-fir produced persistent summer streamflow deficits of 50% relative to reference basins, in plantations aged 25 to 45 years. This result challenges the widespread assumption of rapid "hydrologic recovery" following forest disturbance. Widespread transformation of mature and old-growth forests may contribute to summer water yield declines over large basins and regions around the world, reducing stream habitats and sharpening conflict over uses of water.

Continued research is needed to examine how forest management influences streamflow deficits. Comparative studies, process studies, and modeling are needed to examine legacies of various past and present forestry treatments and effects of native versus non-native tree species on streamflow. In addition, long-term basin studies should be maintained, revived, and extended to a variety of forest types and forest ownerships, in order to discriminate effects of climate versus forest management on water yield and timing, which will be increasingly important in the future.

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LITERATURE CITED

Abatzoglou, J.T., Rupp, D.E. and Mote, P.W., 2014. Seasonal climate variability and change in the Pacific Northwest of the United States. *Journal of Climate*, 27, 2125-2142.

Adam, J.C., Hamlet, A.F. and Lettenmaier, D.P., 2009. Implications of global climate change for snowmelt hydrology in the twenty- first century. *Hydrological Processes*, 23, 962-972.

Amoroso, M.M. and Turnblom, E.C., 2006. Comparing productivity of pure and mixed Douglas-fir and western hemlock plantations in the Pacific Northwest. *Canadian Journal of Forest Research*, *36*, 1484-1496.

Anderson, P., A Rusk, M. Jones, M. Harris, D. Owens, E. Huffman. 2013. Coyote Creek research prospectus including 2011 stand exam data (unpublished report).

Andréassian, V., 2004. Waters and forests: from historical controversy to scientific debate. *Journal of Hydrology*, 291, 1-27.

Arismendi, I., Johnson, S.L., Dunham, J.B., Haggerty, R. and Hockman- Wert, D., 2012. The paradox of cooling streams in a warming world: regional climate trends do not parallel variable local trends in stream temperature in the Pacific continental United States. *Geophysical Research Letters*, 39, L10401, doi:10.1029/2012GL051448.

Arismendi, I., Safeeq, M., Johnson, S.L., Dunham, J.B. and Haggerty, R., 2013. Increasing synchrony of high temperature and low flow in western North American streams: double trouble for coldwater biota? *Hydrobiologia*, 712, 61-70.

Arthur, A.S., 2007. Thirty-five years of forest succession in southwest Oregon: vegetation response to three distinct logging treatments. MS thesis, Oregon State University.

Barnett, T.P., Pierce, D.W., Hidalgo, H.G., Bonfils, C., Santer, B.D., Das, T., Bala, G., Wood, A.W., Nozawa, T., Mirin, A.A. and Cayan, D.R., 2008. Human-induced changes in the hydrology of the western United States. *Science*, 319, 1080-1083.

Beschta, R.L., Pyles, M.R., Skaugset, A.E. and Surfleet, C.G., 2000. Peakflow responses to forest practices in the western cascades of Oregon, USA. *Journal of Hydrology*, 233, 102-120.

Biederman, J.A., Somor, A.J., Harpold, A.A., Gutmann, E.D., Breshears, D.D., Troch, P.A., Gochis, D.J., Scott, R.L., Meddens, A.J.H., and Brooks, P.D., 2015. Recent tree die-off has little effect on streamflow in contrast to expected increases from historical studies, *Water Resources Research*, 51, doi:10.1002/2015WR017401.

Bond, B.J., Jones, J.A., Moore, G., Phillips, N., Post, D. and McDonnell, J.J., 2002. The zone of vegetation influence on baseflow revealed by diel patterns of streamflow and vegetation water use in a headwater basin. *Hydrological Processes, 16*, 1671-1677.

Briggs, D. 2007. Management practices on Pacific Northwest West-side industrial forest lands, 1991-2005: with projections to 2010. Stand Management Cooperative Working Paper No. 6, College of Forest Resources, University of Washington, Seattle.

Brown, A.E., Zhang, L., McMahon, T.A., Western, A.W. and Vertessy, R.A., 2005. A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *Journal of Hydrology, 310*, 28-61.

Budyko, M.I., 1974. Climate and Life, 508 pp. *Academic, San Diego, Calif*, pp.72-191.

Chang, H., Jung, I.W., Steele, M. and Gannett, M., 2012. Spatial patterns of March and September streamflow trends in Pacific Northwest streams, 1958–2008. *Geographical Analysis, 44*, 177-201.

Chang, H., Jung, I.W., Strecker, A., Wise, D., Lafrenz, M., Shandas, V., Moradkhani, H., Yeakley, A., Pan, Y., Bean, R. and Johnson, G., 2013. Water supply, demand, and quality indicators for assessing the spatial distribution of water resource vulnerability in the Columbia River basin. *Atmosphere-Ocean, 51*, 339-356.

Cornish, P.M. and Vertessy, R.A., 2001. Forest age-induced changes in evapotranspiration and water yield in a eucalypt forest. *Journal of Hydrology, 242*, 43-63.

Creed, I.F., Spargo, A.T., Jones, J.A., Buttle, J.M., Adams, M.B., Beall, F.D., Booth, E.G., Campbell, J.L., Clow, D., Elder, K. Green, M.B., Grimm, N.B., Miniat, C., Ramlal, P, Saha, A., Sebestyen, S., Spittlehouse, D., Sterling, S., Williams, M., Winkler, R., Yao, H., 2014. Changing forest water yields in response to climate warming: results from long-term experimental watershed sites across North America. *Global Change Biology, 20*, 3191-3208.

Dai, A., Qian, T., Trenberth, K.E. and Milliman, J.D., 2009. Changes in continental freshwater discharge from 1948 to 2004. *Journal of Climate, 22*, 2773-2792.

Dyrness, C.T. 1967. Mass soil movements in the H.J. Andrews Experimental Forest. Res. Pap. PNW-42. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.

Dyrness, C.T., 1969. Hydrologic properties of soils on three small watersheds in the western Cascades of Oregon. Res. Note PNW-111. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 17 p.

Dyrness, C.T.; Hawk, G. 1972. Vegetation and soils of the Hi-15 watersheds, H.J. Andrews Experimental Forest. Seattle: University of Washington; Coniferous For. Biome Internal Rep. 43. 28 p.

Eberhardt, L.L. and Thomas, J.M., 1991. Designing environmental field studies. *Ecological Monographs*, *61*, 53-73.

Farley, K.A., Jobbágy, E.G. and Jackson, R.B., 2005. Effects of afforestation on water yield: a global synthesis with implications for policy. *Global Change Biology*, *11*, 1565-1576.

Gray, A.N., Spies, T.A. and Easter, M.J., 2002. Microclimatic and soil moisture responses to gap formation in coastal Douglas-fir forests. *Canadian Journal of Forest Research*, *32*, 332-343.

Halpern, C.B., 1989. Early successional patterns of forest species: interactions of life history traits and disturbance. *Ecology*, 70, 704-720.

Halpern, C.B. and Franklin, J.F., 1990. Physiognomic development of Pseudotsuga forests in relation to initial structure and disturbance intensity. *Journal of Vegetation Science*, 1, 475-482.

Halpern, C.B. and Spies, T.A., 1995. Plant species diversity in natural and managed forests of the Pacific Northwest. *Ecological Applications*, 5, 913-934.

Halpern, C.B. and Lutz, J.A., 2013. Canopy closure exerts weak controls on understory dynamics: a 30-year study of overstory–understory interactions. *Ecological Monographs*, 83, 221–237.

Hamlet, A.F. and Lettenmaier, D.P., 2007. Effects of 20th century warming and climate variability on flood risk in the western US. *Water Resources Research*, *43*, W06427, doi:10.1029/2006WR005099.

Harr, R. Dennis; Fredriksen, Richard L.; Rothacher, Jack. 1979. Changes in streamflow following timber harvest in southwestern Oregon. Res. Pap. PNW-249. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 22 p.

Harr, R.D. and McCorison, F.M., 1979. Initial effects of clearcut logging on size and timing of peak flows in a small watershed in western Oregon. *Water Resources Research*, *15*, 90-94.

Harr, R.D. 1981. Some characteristics and consequences of snowmelt during rainfall in western Oregon. *Journal of Hydrology*, 53, 277-304.

Harr, R.D., Levno, A. and Mersereau, R., 1982. Streamflow changes after logging 130-year-old Douglas fir in two small watersheds. *Water Resources Research*, *18*, 637-644.

Harr, R.D. 1986. Effects of clearcutting on rain-on-snow runoff in western Oregon: a new look at old studies. *Water Resources Research*, 22, 1095-1100.

Harrington, C.A. and Reukema, D.L., 1983. Initial shock and long-term stand development following thinning in a Douglas-fir plantation. *Forest Science*, *29*, 33-46.

Hatcher, K.L. and Jones, J.A., 2013. Climate and streamflow trends in the Columbia River basin: Evidence for ecological and engineering resilience to climate change. *Atmosphere-Ocean*, *51*, 436-455.

Hicks, B.J., Beschta, R.L. and Harr, R.D., 1991. Long-term changines in streamflow following logging in western Oregon and associated fisheries implications. *Journal of the American Water Resources Association*, *27*, 217-226.

Hodgkins, G.A., Dudley, R.W. and Huntington, T.G., 2003. Changes in the timing of high river flows in New England over the 20th century. *Journal of Hydrology*, *278*, 244-252.

Hodgkins, G.A., R.W. Dudley, and T.G. Huntington, 2005. Summer low flows in New England during the 20th century. *Journal of the American Water Resources Association*, 41, 403-412.

Hornbeck, J.W., Martin, C.W. and Eagar, C., 1997. Summary of water yield experiments at Hubbard Brook experimental forest, New Hampshire. *Canadian Journal of Forest Research*, *27*, 2043-2052.

Isaak, D.J., Wollrab, S., Horan, D. Chandler, G. 2012. Climate change effects on stream and river temperatures across the northwest U.S. from 1980-2009 and implications for salmonid fishes. *Climatic Change* 113, 499-524.

Jefferson, A., Nolin, A., Lewis, S. and Tague, C., 2008. Hydrogeologic controls on streamflow sensitivity to climate variation. *Hydrological Processes*, *22*, 4371-4385.

Jennings, K., Jones, J.A., 2015. Precipitation-snowmelt timing and snowmelt augmentation of large peak flow events, western Cascades, Oregon. *Water Resources Research*, 51, 7649–7661. doi: 10.1002/2014WR016877

Jones, J.A. and Grant, G.E., 1996. Peak flow responses to clear- cutting and roads in small and large basins, western Cascades, Oregon. *Water Resources Research*, *32*, 959-974.

Jones, J.A., 2000. Hydrologic processes and peak discharge response to forest removal, regrowth, and roads in 10 small experimental basins, western Cascades, Oregon. *Water Resources Research*, *36*, 2621-2642.

Jones, J.A. and Post, D.A., 2004. Seasonal and successional streamflow response to forest cutting and regrowth in the northwest and eastern United States. *Water Resources Research*, 40, W05203, doi:10.1029/2003WR002952.

Jones, J.A. and Perkins, R.M., 2010. Extreme flood sensitivity to snow and forest harvest, western Cascades, Oregon, United States. *Water Resources Research*, 46, W12512, doi:10.1029/2009WR008632.

Jones, J.A., 2011. Hydrologic responses to climate change: considering geographic context and alternative hypotheses. *Hydrological Processes*, *25*, 1996-2000.

Jones, J.A. Creed, I.F., Hatcher, K.L., Warren, R.J., Adams, M.B., Benson M.H., Boose, E., Brown, W.A., Campbell, J.L., Covich, A., Clow, D.W., Dahm, C.N., Elder, K., Ford, C.R., Grimm, N.B., Henshaw, D.L., Larson, K.L., Miles, E.S., Miles, K.M., Sebestyen, S.D., Spargo, A.T., Stone, A.B., Vose, J.M., and Williams, M.W., 2012. Ecosystem processes and human influences regulate streamflow response to climate change at long-term ecological research sites. *BioScience*, 62:390-404.

Kennedy, A.M., Garen, D.C. and Koch, R.W., 2009. The association between climate teleconnection indices and Upper Klamath seasonal streamflow: Trans-Niño Index. *Hydrological processes*, *23*, 973-984.

Special Issue Article
Lara, A., Villalba, R. and Urrutia, R., 2008. A 400-year tree-ring record of the Puelo River summer–fall streamflow in the Valdivian Rainforest eco-region, Chile. *Climatic Change*, *86*, 331-356.

Lins, H.F. and Slack, J.R., 1999. Streamflow trends in the United States. *Geophysical Research Letters*, *26*, 227-230.

Lins, H.F. and Slack, J.R., 2005. Seasonal and regional characteristics of US streamflow trends in the United States from 1940 to 1999. *Physical Geography*, *26*, 489-501.

Littell, J.S., Oneil, E.E., McKenzie, D., Hicke, J.A., Lutz, J.A., Norheim, R.A. and Elsner, M.M., 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. *Climatic change*, *102*, 129-158.

Little, C., Lara, A., McPhee, J. and Urrutia, R., 2009. Revealing the impact of forest exotic plantations on water yield in large scale watersheds in South-Central Chile. *Journal of Hydrology*, *374*, 162-170.

Little, C., Cuevas, J.G., Lara, A., Pino, M. and Schoenholtz, S., 2014. Buffer effects of streamside native forests on water provision in watersheds dominated by exotic forest plantations. *Ecohydrology*, *8*, 1205-1217.

Luce, C.H. and Holden, Z.A., 2009. Declining annual streamflow distributions in the Pacific Northwest United States, 1948–2006. *Geophysical Research Letters*, 36, L16401, doi:10.1029/2009GL039407.

Luce, C.H., Abatzoglou, J.T. and Holden, Z.A., 2013. The missing mountain water: Slower westerlies decrease orographic enhancement in the Pacific Northwest USA. *Science*, *342*, 1360-1364.

Lutz, J.A., Halpern, C.B., 2006. Tree mortality during early forest development: a long-term study of rates, causes, and consequences. *Ecological Monographs*, 76, 257-275.

Maguire, D.A., Kanaskie, A., Voelker, W., Johnson, R. and Johnson, G., 2002. Growth of young Douglas-fir plantations across a gradient in Swiss needle cast severity. *Western Journal of Applied Forestry*, 17, 86-95.

Marshall, D.D. and Curtis, R.O., 2002. Levels-of-Growing-Stock Cooperative Study in Douglas-fir: Report No. 15–Hoskins: 1963–1998. USDA Forest Service Pacific Northwest Research Station Research Paper PNW-RP-537.

Marshall, D.D. and Turnblom, E.C., 2005. Wood productivity of Pacific Northwest Douglas-fir: estimates from growth-and-yield models. *Journal of Forestry*, *103*, 71-72.

Marshall, J.D., Waring, R.H., 1984. Conifers and broadleaf species: stomatal sensitivity differs in western Oregon. *Canadian Journal of Forest Research*, 14, 905-908.

Marshall, J.D., Waring, R.H., 1986. Comparison of methods of estimating leaf-area index in old-growth Douglas-fir. *Ecology*, 67, 975-979.

McCabe, G.J. and Wolock, D.M., 2002. A step increase in streamflow in the conterminous United States. *Geophysical Research Letters*, *29*, 2185, doi:10.1029/2002GL015999.

Moore, G.W., Bond, B.J., Jones, J.A., Phillips, N. and Meinzer, F.C., 2004. Structural and compositional controls on transpiration in 40-and 450-year-old riparian forests in western Oregon, USA. *Tree Physiology*, *24*, 481-491.

Mote, P.W., Parson, E.A., Hamlet, A.F., Keeton, W.S., Lettenmaier, D., Mantua, N., Miles, E.L., Peterson, D.W., Peterson, D.L., Slaughter, R. and Snover, A.K., 2003. Preparing for climatic change: the water, salmon, and forests of the Pacific Northwest. *Climatic Change*, 61, 45-88.

Nolin, A.W. and Daly, C., 2006. Mapping "at risk" snow in the Pacific Northwest. *Journal of Hydrometeorology*, 7, 1164-1171.

Perkins, R.M., Jones, J.A., 2008. Climate variability, snow, and physiographic controls on storm hydrographs in small forested basins, western Cascades, Oregon. *Hydrological Processes*, 22, 4949-4964.

Perry, D.A., Hessburg, P.F., Skinner, C.N., Spies, T.A., Stephens, S.L., Taylor, A.H., Franklin, J.F., McComb, B. and Riegel, G., 2011. The ecology of mixed severity fire regimes in Washington, Oregon, and Northern California. *Forest Ecology and Management*, *262*, 703-717.

Rothacher, J. 1965. Streamflow from small watersheds on the western slope of the Cascade Range of Oregon. *Water Resources Research*, 1, 125-134.

Rothacher, J. 1970. Increases in water yield following clear-cut logging in the Pacific Northwest. *Water Resources Research*, 6, 653-658.

Rothacher, J., Dyrness, C.T., and Fredriksen, R.L., 1967. Hydrologic and related characteristics of three small watersheds in the Oregon Cascades. Portland, OR: U.S.

Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 54 p.

Rothacher, J. 1969. A Study of the effects of timber harvesting on small watersheds in the Sugar Pine Douglas-fir Area of S.W. Oregon. Coyote Creek establishment report. Unpublished report, 12 p.

Scott, D.F., 2005. On the hydrology of industrial timber plantations. *Hydrological Processes*, *19*, 4203-4206.

Stewart, I.T., Cayan, D.R. and Dettinger, M.D., 2004. Changes in snowmelt runoff timing in western North America under abusiness as usual'climate change scenario. *Climatic Change*, *62*, 217-232.

Stewart, I.T., Cayan, D.R. and Dettinger, M.D., 2005. Changes toward earlier streamflow timing across western North America. *Journal of climate*, *18*, 1136-1155.

Sun, G., Zhou, G., Zhang, Z., Wei, X., McNulty, S.G. and Vose, J.M., 2006. Potential water yield reduction due to forestation across China. *Journal of Hydrology*, *328*, 548-558.

Swanson, F.J. and James, M.E., 1975. Geomorphic history of the lower Blue River-Lookout Creek area, Western Cascades, Oregon. *Northwest Science*, *49*, 1-11.

Swanson, F.J. and Swanston, D.N., 1977. Complex mass-movement terrains in the western Cascade Range, Oregon. *Reviews in Engineering Geology*, *3*, 113-124.

Tepley, A.J., 2010. Age structure, developmental pathways, and fire regime characterization of Douglas-fir/Western Hemlock Forests in the Central Western Cascades of Oregon. PhD thesis, Oregon State University.

Tepley, A.J., Swanson, F.J. and Spies, T.A., 2013. Fire-mediated pathways of stand development in Douglas-fir/western hemlock forests of the Pacific Northwest, USA. *Ecology*, *94*, 1729-1743.

van Dijk, A.I. and Keenan, R.J., 2007. Planted forests and water in perspective. *Forest Ecology and Management*, *251*, 1-9.

Van Mantgem, P.J., Stephenson, N.L., Byrne, J.C., Daniels, L.D., Franklin, J.F., Fulé, P.Z., Harmon, M.E., Larson, A.J., Smith, J.M., Taylor, A.H. and Veblen, T.T., 2009. Widespread increase of tree mortality rates in the western United States. *Science*, *323*, 521-524.

Vörösmarty, C.J., Green, P., Salisbury, J. and Lammers, R.B., 2000. Global water resources: vulnerability from climate change and population growth. *Science*, *289*, 284-288.

Weisberg, P.J. and Swanson, F.J., 2003. Regional synchroneity in fire regimes of western Oregon and Washington, USA. *Forest Ecology and Management*, *172*, 17-28.

Wondzell, S.M., Gooseff, M.N. and McGlynn, B.L., 2007. Flow velocity and the hydrologic behavior of streams during baseflow. *Geophysical Research Letters*, 34, L24404, doi:10.1029/2007GL031256.

Zhang, L., Dawes, W.R. and Walker, G.R., 2001. Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research*, 37, 701-708.

Table 1: Name and abbreviation, area, elevation range, natural vegetation, streamflow gaging method and record length, harvest treatment, logging methods, and treatment dates for basins used in this study. Sources: Harr *et al.*, 1979; Rothacher, 1965; Harr *et al.*, 1982; Rothacher *et al.*, 1967; Jones and Post, 2004.

Basin name	Area (ha)	Elevation range (m)	Natural vegetation	Streamflow record length, instrumentation[b]	Treatment, date[a]	Logging Method
Coyote 1 COY 1	69.2	750-1065	Mixed conifer	1963-81 V; 2001-present V	Roads 1970; 50% over-story selective cut, 1971	Tractor yarded
Coyote 2 COY 2	68.4	760-1020	Mixed conifer	1963-81 V; 2001- present V	Permanent roads 1970; 30% 2 to 3-ha patch cuts, 1971	16% high-lead cable yarded; 14% tractor yarded.
Coyote 3 COY 3	49.8	730-960	Mixed conifer	1963-81 V; 2001- present V	Permanent roads 1970; 100%; clearcut 1971	77% high-lead cable yarded; 23% tractor yarded.
Coyote 4 COY 4	48.6	730-930	Mixed conifer	1963-81 V; 2001- present V	Reference	N/A
Andrews 1 AND 1	95.9	460-990	450-500-yr–old Douglas-fir forest	1952-present (1952-present T [rebuilt 1956]; 1999-present SV)	100% clearcut 1962-1966	100% skyline yarded
Andrews 2 AND 2	60.7	530-1070	450-500-yr–old Douglas-fir forest	1952-present (1952-present T; 1999 - present SV)	Reference	N/A
Andrews 3 AND 3	101.2	490-1070	450-500-yr–old Douglas-fir forest	1952-2005 T; 1999 -present SV	Roads 1959; 30% patch-cut 1962	30% high-lead cable yarded
Andrews 6 AND 6	13.0	863-1013	130- 450-year old Douglas-fir forest	1964-present; (1964 – 1997 H; 1997-present T; 1998 present SV)	Roads; 100% clearcut 1974; broadcast burn 1975	90% high-lead cable yarded; 10% tractor yarded
Andrews 7 AND 7	15.4	908-1097	130- 450-year old Douglas-	1964-1987; 1995-present (1964 – 1997 H;	Roads 1974; 60% shelterwood	40% skyline yarded;

			fir forest	1997- present T; 1998 - present SV)	cut 1974; remaining overstory cut 1984; broadcast burn lower half of WS 1975; 12% basal area thin 2001	60% tractor yarded.
Andrews 8 AND 8	21.4	955-1190	130- 450-year old Douglas-fir forest	1964-present (1964 –1987 H; 1987 present T; 1973 – 1979 SV, 1997 – present SV)	Reference	N/A
Andrews 9 AND 9	9	425-700	130- 450-year old Douglas-fir forest	1969-present (1969 -1973 H; 1973 present T; 1973 – 1979 SV, 1997 present SV)	Reference	N/A
Andrews 10 AND 10	10	425-700	130- 450-year old Douglas-fir forest	1969-present (1969 -1973 H; 1973 present T; 1973 – 1979 SV, 1997 - present SV)	100% clear-cut 1975; no burn	100% high-lead cable yarded

a Broadcast burns were controlled burns over the cut area intended to consume logging debris.

b H: H-flume; T: trapezoidal flume; V: v-notch weir or plate. Summer V-notch weirs have been used for improved discharge measurements over the following periods: since 1999 at Andrews 1, 2, and 3; since 1998 at Andrews 6, 7, and 8; and from 1969 to 1973 and since 1997 at Andrews 9 and 10.

Table 2. Vegetation characteristics of the study basins, sampled over the period 1981 to 2011. Basal area is mean ± standard deviation. PSME = *Pseudotsuga menziesii* (Douglas-fir), TSHE = *Tsuga heterophylla* (western hemlock), THPL = *Thuja plicata* (western red cedar), ABCO = *Abies concolor* (white fir), CADE = *Calocedrus decurrens* (California incense cedar), PILA = *Pinus lambertiana* (sugar pine).

					Basal area (m^2/ha)	Basal area As %							Stem density (stems/ha)	
Watershed	N of plots	Plot size (m^2)	Year	Age	All	PSME	TSHE	THPL	ABCO	CADE	PILA	Other[a]	All	PSME
Treated patches														
AND 1	132	250	2007	40	33 ± 14	85	3	1	0	0	0	11	1454	919
AND 3	61	250	2007	43	35 ± 12	80	11	2	0	0	0	7	1857	621
AND 6	22	250	2008	34	35 ± 9	77	11	9	0	0	0	3	1107	699
AND 7	24	250	2008	24	23 ± 10	70	9	4	0	0	0	17	900	551
AND 10	36	150	2010	35	27 ± 12	81	4	2	0	0	0	13	893	437
COY 1[be]	--[f]	--[f]	2011	35-200[g]	66	56	5	0	17	12	5	5	992	194
COY 2[c]	4	150	2006	35	31 ± 12	82	0	0	0	13	0	5	1733	1150
COY 3[c]	4	150	2006	35	45 ± 13	80	0	0	0	10	0	10	1533	1083
Reference														
AND 2	67	250	1981	150-475[d]	69 ± 29	70	24	2	0	0	0	4	262	67
	67	250	2006	175-500[d]	72 ± 29	65	29	2	0	0	0	4	438	87
AND 8	22	1000	2003	175-500[d]	86 ± 24	64	26	9	0	0	0	2	580	144
	22	1000	2009	175-500[d]	89 ± 24	64	26	9	0	0	0	2	565	139
AND 9	16	1000	2003	175-500[d]	84 ± 25	92	4	0	0	0	0	4	630	434
	16	1000	2009	175-500[d]	85 ± 25	92	5	0	0	0	0	3	602	417
COY 2[b]	--[f]	--[f]	2011	150-350[g]	89	61	0	0	10	17	11	1	1169	172
COY 4[b]	--[f]	--[f]	2011	150-350[g]	66	55	5	0	18	11	5	6	975	183

-- Not available.
a Other (at Coyote Creek) includes *Arbutus menziesii* (madrone), *Pinus ponderosa* (ponderosa pine), and *Taxus brevifolia* (Pacific yew). Other (at the Andrews Forest) includes *Acer macrophyllum* (bigleaf maple), *Castanopsis chrysophylla* (giant chinquapin), and *Prunus emarginata* (bitter cherry).

b 2011 stand exam data for matrix (not forest plantations) from Anderson *et al*., 2013.
c Source: Arthur, 2007.
d Multi-age stand with mixed-severity fire history.
e Coyote 1 was sampled in 2006 (Arthur, 2007) and 2011 (Anderson *et al*., 2013).
f Data from a forestry stand examination, not from plots, and no standard error is provided.
g Source: Rothacher, 1969.

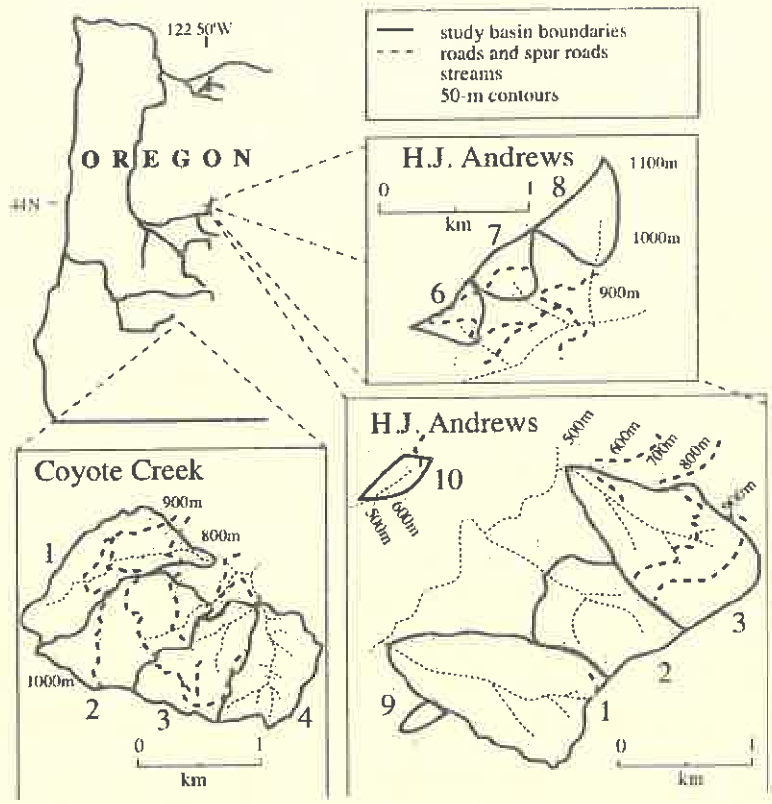


Figure 1. Location of study basins in western Oregon.

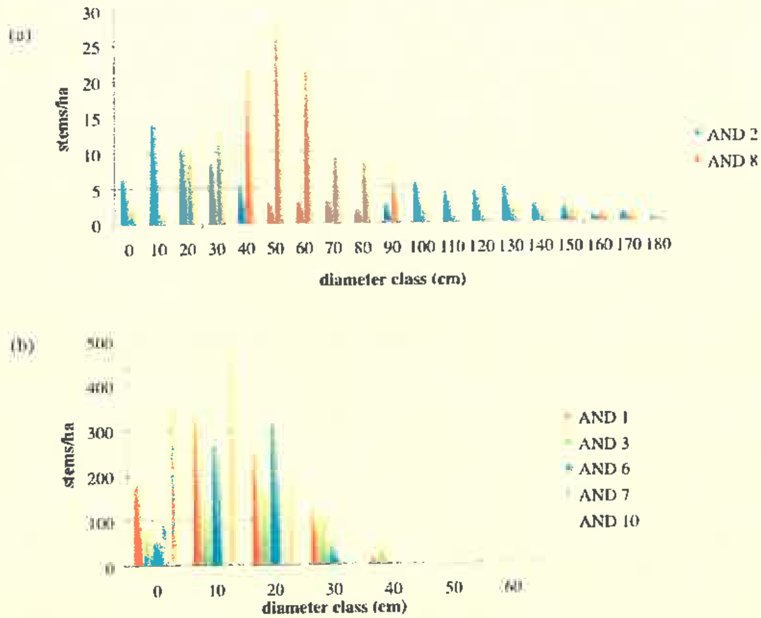


Figure 2. Size class distributions of Douglas-fir (Pseudotsuga menziesii, PSME) in plantations and reference basins in the Andrews Forest. (a) reference basins used in this study: AND 2 (2006), AND 8 (2009). (b) basins with young Douglas-fir plantations: AND 1 (aged 40 yrs, 2007), AND 3 (clearcut patches, aged 43 yrs, 2007), AND 6 (aged 34 yrs, 2008), AND 7 (aged 34 yrs, 2008), AND 10 (aged 35 yrs, 2010).

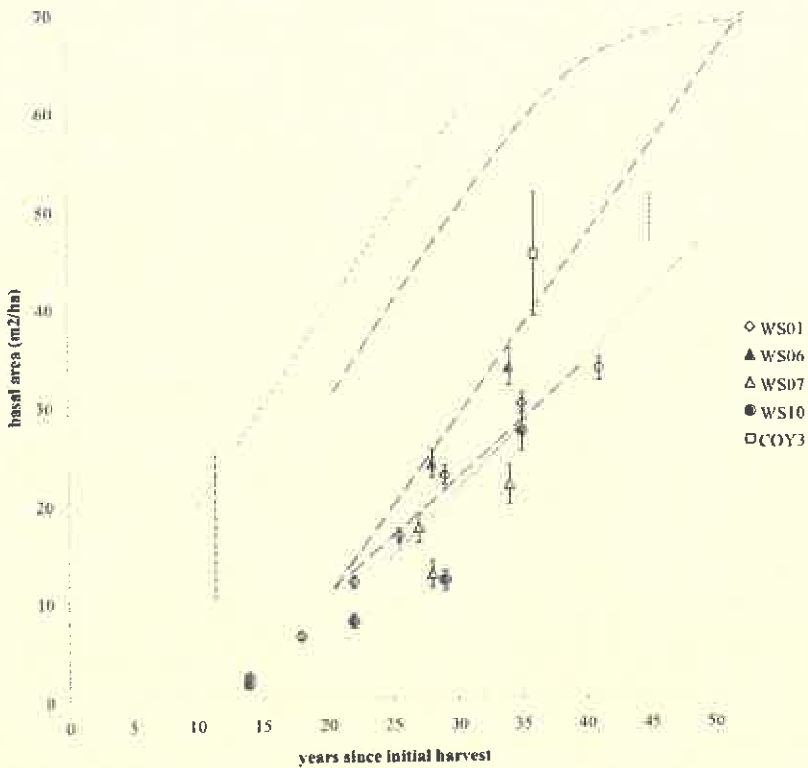


Figure 3. Basal area as a function of time since treatment forest plantations in this study, and comparable values from forest plantations in the region. Values are means ± standard error from numbers of plots shown in Table 2. The diagonal thick grey dashed lines are the basal area reported from control (unthinned) plots (upper line), heavily thinned plots (lower line) and lightly thinned plots (middle line) in the Hoskins levels-of-growing-stock (LOGS) installation (site II) in western Oregon (Marshall and Curtis 2002). The diagonal thin grey dashed line indicates average annual basal area for Douglas-fir plantations on relatively high site productivity locations affected by various levels of infection from Swiss needle cast in the Oregon Coast Range (Maguire et al., 2002). The diagonal thin grey dotted line indicates basal areas for experimental Douglas-fir plantations at low site productivity locations (site V) at Wind River (100 km N of the Andrews Forest, at a similar elevation to the experimental basins) (Harrington and Reukema 1983). The vertical grey dotted line is estimated Douglas-Fir basal area from growth and yield models for 45-yr-old stands (Marshall and Turnblom 2005). The vertical grey dashed line is range of basal areas in stands of Douglas-fir, western hemlock, and mixtures (Amoroso and Turnblom 2006).

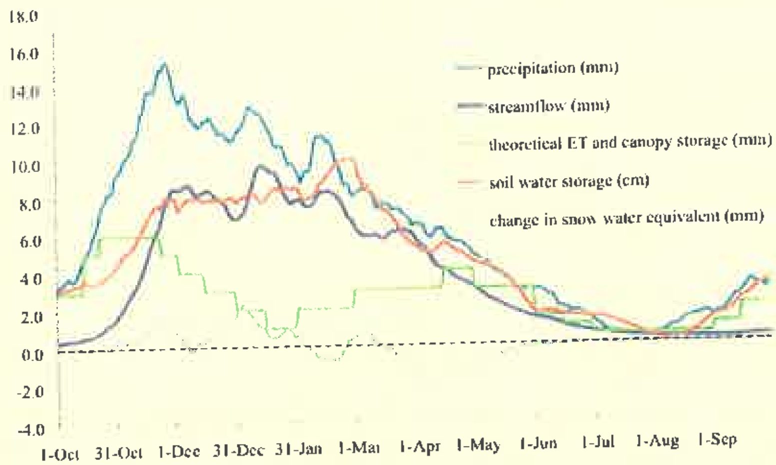


Figure 4. Water balance of mean daily values of precipitation (P), streamflow (Q), ET, snow water equivalent (N), and soil water storage (S) in AND 2, based on data from 1953 to 2003 water years, where S = P – Q – ET - ΔN. Daily ET was estimated from the response of AND 1/2 to clearcutting calculated by Jones and Post (2004) and from summer sapflow measured in AND 2 by Moore et al., (2004). Snow water equivalent was based on average modeled daily values from Perkins and Jones (2008).

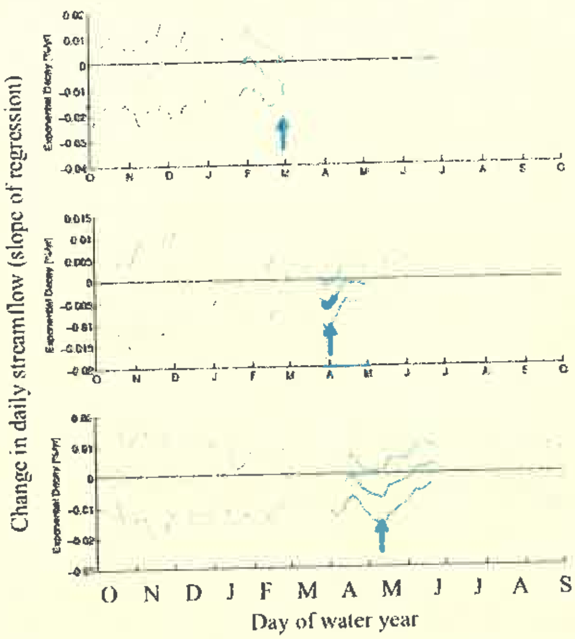
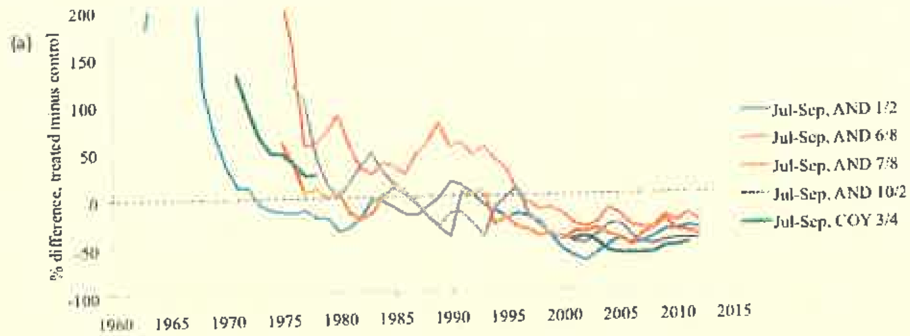


Figure 5. Streamflow change for period of record to 1996, by day of water year (October to September) for three reference basins: (a) AND 9 – 400-700 m; (b) AND 2 – 500-1000 m; and (c) AND 8 – 800-1100 m. The green line is the trend in streamflow (positive or negative) on that day of the year, relative to the long-term mean streamflow on that day (indicated as zero). Black lines are the 95% confidence interval around the trend. Blue arrows indicate days of declining streamflow, and dark blue lines are days of significant declines in streamflow; declines are significant only at AND 2. Shaded boxes show the period of snowmelt from Perkins and Jones (2008). K. Moore, unpublished data.



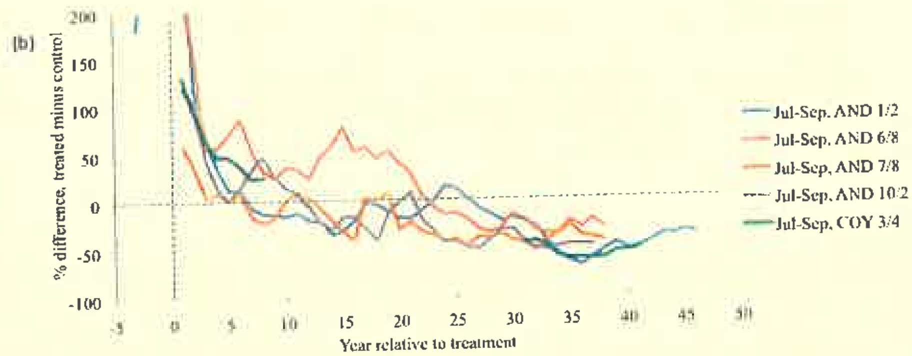


Figure 6. Trends in average daily streamflow (July through September) in basins with forest plantations as a percent of streamflow in the reference basin, for five basin pairs with 100% clearcut basins. (a) by year. (b) by time since treatment. Basin pair names include treated/reference. Percents are 3-year running means. Grey box is the mean ± the standard error of the treated-reference basin relationship from July to September during the pre-treatment period.

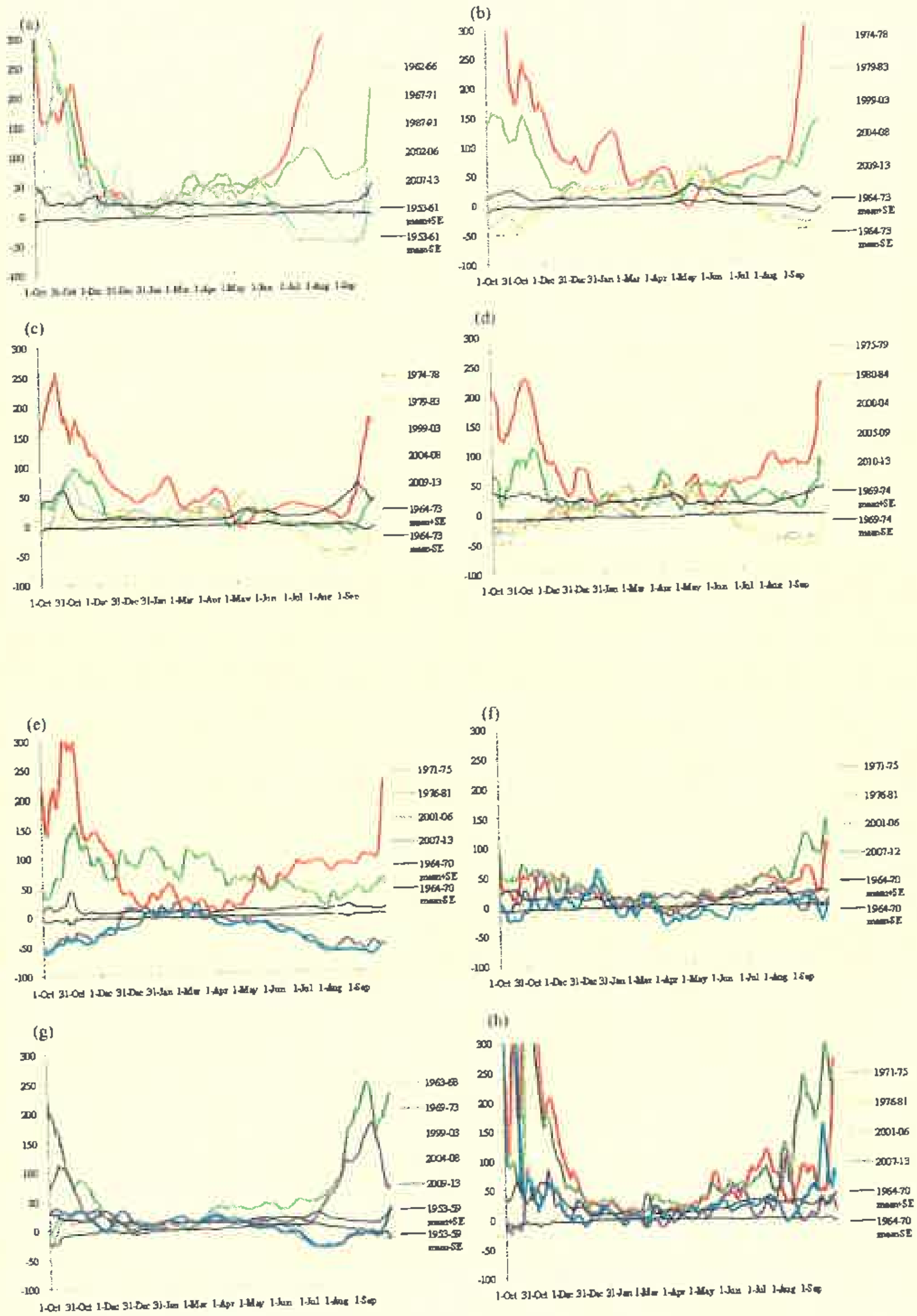


Figure 7. Percent change in streamflow by day of water year in five-year periods after forest harvest and plantation establishment for eight pairs of basins. (a) AND 1 (100% clearcut 1962-66) vs. AND 2 (reference), (b) AND 6 (100% clearcut 1974) vs. AND 8 (reference), (c) AND 7 (50% cut 1974, remainder cut 1984) vs. AND 8 (reference), (d) AND 10 (100% clearcut 1975) vs. AND 2 (reference), (e) COY 3 (100% clearcut 1970) vs. COY 4

(reference), (f) COY 1 (50% cut 1970) vs. COY 4 (reference), (g) AND 3 (25% patch cut 1963) vs. AND 2 (reference), (h) COY 2 (30% patch cut 1970) vs. COY 4 (reference). Black lines represent the mean and standard error of the percent difference between the treated and reference basins during the pre-treatment period. Dashed grey line is a 50% decline in streamflow at the treated basin relative to its relationship to the reference basin during the pre-treatment period.

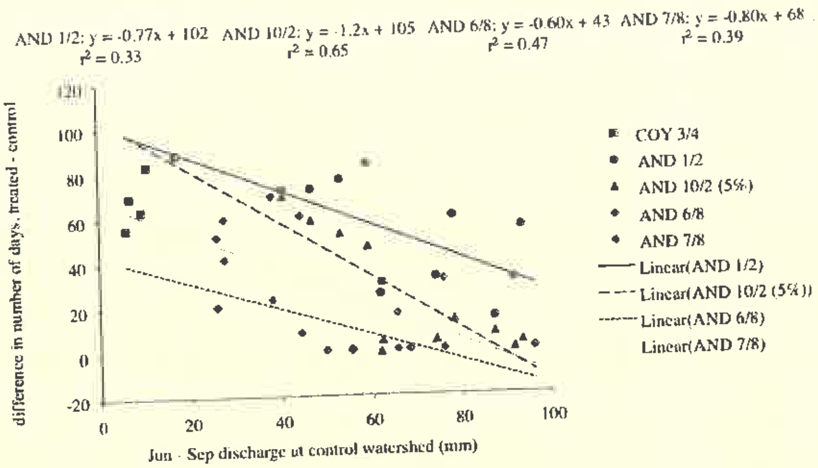


Figure 8. Difference in number of days in the 1st and 5th (AND 10/2) flow percentiles from 1995 to 2005, in basins with 25 to 40-yr-old plantations relative to reference (old-growth) basins. A value of zero on the Y-axis indicates that the basin with forest plantation had the same number of days in the low flow percentile as the reference basin; a value of 80 indicates that the basin with forest plantation had 80 more days in the low flow percentile than the reference basin. Negative slopes of regression lines indicate that the duration of low streamflow increased in drier summers in the forest plantation, relative to the reference basin. The 5th percentile was used for AND 10/2 because only a few years had >0 days in the 1% category.

Councillor Llewellyn (verbal report)

I was at the Health Network meeting this week in Campbell River and we had a really nice presentation from a fellow that started an initiative to get kids out playing. At this point we don't have that problem here as they kids don't have cell service or great internet access so they tend to be what they call more "free range" kids. There was a new buzz word called "physical literacy". This was the first time I heard this idea or was aware of it. He was talking about maybe communities like this and Gold River haven't gotten into the cell phones and computers but we need to get a head of it before that stuff comes here to get them thinking that yes that is a nice alternative but this is more fun.

I was also at the meeting here for the rural health sites visit and was very impressed with the number of people that turned out. They were really impressed with the number of people that came out. We are very active, involved community.

Fowler/Llewellyn: VOT 351/2019
THAT these Council reports be received. **CARRIED**

Bylaws
None.

L. Correspondence

1 **Ted Olynyk, Community Relations Manager, BC Hydro Re: 2019 UBCM Convention**

2 **Rosemary Bonanno, Executive Director, Vancouver Island Regional Library Board Re: Proposed Tahsis Branch**

3 **Hon. Claire Trevena, MLA, North Island Re: BC Hydro future rate designs**

4 **MP Rachel Blaney- Letter and report to Minister Wilkinson**

5 **Ministry of Citizens' Services, Information Access Operations Re: Request for Access to Records - Freedom of Information and Protection of Privacy Act (FOIPPA)**

Fowler/Llewellyn: VOT 352/2019
THAT these correspondence items received. **CARRIED**

Fowler/Elder: VOT 353/2019
THAT all item 2,3,4 and 5 be pulled for discussion. **CARRIED**

L1 Brief discussion

L2 **Fowler/Llewellyn: VOT 354/2019**

THAT Council consider Tahsis branch location options, prepared by staff, as part of the 2020-2024 financial plan work up. **CARRIED** 1 **"no" vote registered Councillor Elder**

L3 Council was encouraged to login and individually complete the survey at https://www/bcuc.com

L4 Brief discussion followed.

L5 The CAO spoke to this correspondence item.

M. New Business
None.

N. Public Input #2
A member of the public had questions regarding salmon fishing closures to which the Mayor, Council and Staff responded.

Recess

Fowler/Elder: VOT 355/2019

THAT the Regular Council meeting recess to go in to the Committee of the Whole meeting at 8:30 p.m.

Reconvene:

Fowler/Elder: VOT 356/2019

THAT the Regular Council meeting reconvene at 9:46 p.m.

Rise and Report

July 2nd Committee of the Whole Meeting Fowler: COW 61/2019

THAT the Tahsis Delegation apply to meet with Ministers: Donaldson, Trevena, Heyman, Popham, Dix (subject to clarifying nurse salary discrepancies), and Anne Kang, Parliamentary Secretary for Seniors and that the Delegation also seek meetings with Telus, BC Hydro and the BC Wildfire Service and EMBC (joint meeting) at the 2019 UBCM Convention.

Adjournment

Llewellyn/Fowler: VOT 357/2019

THAT the meeting be adjourned at 9:46p.m. **CARRIED**

Certified Correct this

6th Day of August 2019.

Chief Administrative Officer

F1

Minutes

Meeting	**Regular Council**
Date	**18 June 2019**
Time	**7:00 PM**
Place	**Municipal Hall - Council Chambers**

Present
Mayor Martin Davis
Councillor Bill Elder
Councillor Sarah Fowler
Councillor Lynda Llewellyn

Regrets
Councillor Josh Lambert

Staff
Mark Tatchell, Chief Administrative Officer
Janet StDenis, Finance & Corporate Services Manager

Public
3 members of the public

A. Call to Order

Mayor Davis called the meeting to order at 7:01 p.m.
Mayor Davis acknowledged and respected that Council is meeting upon Mowachaht/ Muchalaht territory

B. Introduction of Late Items and Agenda Changes

Additional information and a Report to Council was provided for "H1" International Peak Properties Corp; The Village of Tahsis' 2018 Statement of Financial Information (SOFI) document was added; the delegation for Steve Savola, Manager, Conuma Cable Systems Inc under "D1" was deleted, the New Horizons Grant Application under new business as "M1" was also deleted.

C. Approval of the Agenda

Fowler/Llewellyn: VOT 328/2019
THAT the Agenda for the June 4, 2019 Regular Council meeting be adopted as amended. **CARRIED**

D. Petitions and Delegations

None.

E. Public Input # 1

None.

F. Adoption of the Minutes

1 **Minutes of the Regular Council meeting held on June 4th, 2019**

Fowler/Llewellyn: VOT 329/2019

THAT Coucillor Fowler's Report to Council for the June 4th minutes be amended by changing the location of the NSWS green crab awareness event from "Westview Marina" to the "Tahsis Recreation Centre" **CARRIED**

Llewellyn/Elder: VOT 330/2019

THAT the Regular Council meeting minutes of June 4, 2019 be adopted as amended. **CARRIED**

G. Rise and Report

None.

H. Business Arising

1 **International Peak Properties Corp (Owner) of Lot A, DL 443, Nootka Land District; representation by the Owner to Council requesting Council reconsider the Remedial Action Order issued by Council dated May 8th.**

The CAO spoke to this Remedial Action Order request for reconsideration summarizing the Owner's position. A brief discussion followed.

Llewellyn/Elder: VOT 331/2019

TO receive the reconsideration request from the Owner under s. 78 of the Community Charter and documents related to this matter. **CARRIED**

Llewellyn/Fowler: VOT 332/2019

TO confirm the remedial action requirements as stated in the May 8th Order and provide notice of this decision in accordance with s. 77(1) and (2). **CARRIED**

2 **Report to Council Re: Village of Tahsis' 2018 Statement of Financial Information (SOFI) :**

Fowler/Llewellyn: VOT 333/2019

THAT the Village of Tahsis' 2018 Statement of Financial Information (SOFI) be received. **CARRIED**

Llewellyn/Elder VOT 334/2019

THAT the Village of Tahsis' statement of Financial Information (SOFI) be approved and posted to the Village's website. **CARRIED**

J. Council Reports
Mayor Davis

A group of municipal politicians on Vancouver Island is forming a working group to draft an Island and Coastal Community Climate Leadership Plan by the end of 2020. Following positive discussions with the federal Minister of Environment and Climate change, they have also asked the feds for $1.3 million to help in drafting this plan. It is meant to partner larger communities that have greater financial resources with our small rural communities to develop strategies that work for all. This means goals such as reducing greenhouse gases, increasing energy efficiencies, reducing pollution and doubling our protection of natural areas, amongst many others.

This past Wednesday, I attended a Strathcona Regional District board meeting. After bringing forward a successful motion to engage with the working group, I was elected to represent the regional district on it. This will involve engaging with the representatives of all our communities and rural areas for input and to report back on our progress. First Nation communities have also been invited to join this working group separately but I will engage with those within our region as appropriate. I consider this a real opportunity and a challenge and am looking forward to it! Our first meeting will be in August.

Also, a shout out to our own councillor, Sarah Fowler, who pushed this issue hard and lit a fire under my butt to do something! Thanks for that!

On Thursday, I attended a strategic planning session of the Strathcona Regional District. This is a brainstorming session where we look at new ways to improve the RD and its services and programs for the communities it serves. I would like to say it was productive but unfortunately it was marred by a bit of sniping by certain representatives and attempts to refight old battles. So it is when you put a group of strong-willed politicians in a room together. Having said that, I believe the SRD is a very progressive organization and some good ideas came forward. I was pushing the concept of community resiliency - that is, communities should be more self-sustaining in the event of natural or other disasters. I believe strongly that communities should take more control of their own energy and food production and be able to sustain themselves to a larger degree than we are currently. This will make our province and country stronger in the long run if this is adopted as a fundamental principle of governance. Anyway, there will be more to report when the document comes forward from this session. I would like to say that the SRD staff did an excellent job and none of this reflects badly on them.

Yesterday, there was a presentation in Tahsis by Strathcona Regional District as well as provincial government reps and communication and tech consultants regarding the Connected Coast strategy. This will bring high speed internet to Tahsis with speeds approaching 50mbps download and 10 mbps upload and will be completed in the next couple of years. Submarine fibre optic cable is planned which will encircle the Island and also go up the mainland coast to Prince Rupert and Haida Gwaii. Our segment will service the communities of Gold River, Yuquot, Tahsis, Zeballos, Ocluje and Kyuquot. Encircling the Island will assure redundancy that will build in some resiliency in anticipation of natural events such as earthquakes which could break the cable. This program is important for economic growth here as it will allow people to move here that need fast, reliable internet for their work. It will also be useful for programs such as telehealth, which is online health consulting, and online education.

Councillor Elder

No report

Councillor Fowler (Verbal Report)

Yesterday the biologist who chaired the Nootka Sound Watershed Society, Roger Dunlop discussed an error on the map WFP put on the front page of the TSR draft analysis information. We discussed the finding of sea lice on juvenile salmon during the beach seining data collection and the fish farm practices of removing lice with hydrogen peroxide. Rather then put them into the acid bath they have on the premise they get dumped into the marine ecosystem, migratory routes of wild salmon. He also asked if there was interest in the Martin Sheen coming to other communities from Tofino. We also discussed the culvert or bridge needed for Pete`s pond tributary and how best to support spawning . Further to the Timber supply review process he explained how old growth trees can sequester carbon but juvenile cedar are thirsty and are drinking 50% of the local rivers water, which equates to unlicensed extraction. This brings us to the question of fish species and the inelastic demand they have for water.

Andrew Weaver spoke on the radio today about the decade for climate action as predicted by the IPPC. This is the timeline that a timber supply review process is also forecasting for. Upon spending some time in Port McNeill since the last meeting. This has given me a chance to take notes at the intersection of forestry and marine tourism. the mount Waddington region puts on a world class logger sports event and I marvelled at how organized everything was. Yet I read in the newspaper there the headline. " lumber heads for biggest rally in 24 years." Last Thursday on the Chicago mercantile exchange had lumber futures hitting the maximum $373.80 per 1000 board feet, up 19$, the biggest weekly gain since 1995; signaling the end of over production. We have higher production costs in Canada but senior analysis from Bloomberg Intelligence, Joshua Zaret observing mill curtailments for WFP, West Fraser, Norbard Inc, and Vancouver based Canfor. He said "when you see capacity closures it means you`re probably not that far from the bottom of the pricing cycle."

3 attachments

1) Nootka Sound Watershed Society Draft Agenda- Monday June 17, 2019

2) Nootka Sound Watershed Society Draft Minutes - Wednesday May 29, 2019

3) Conuma Hatchery 2019 Fall Hiring- Instructions for obtaining security clearance in preparation for fall hiring

/

Nootka Sound Watershed Society
Draft Agenda
Monday June 17th 2019
Conuma River Hatchery
7pm

1. Welcome and Introductions:

Attendance:

2. Review and adopt of the Agenda – **Motion to accept: 2nd:**
3. Review and adopt of the minutes from May 29th 2019 meeting – **Motion to accept: 2nd:**
4. Review of action items from May 29th 2019 meeting -

Action Items: NEW ITEMS

Action	Who	Completed
Reach out to Dunlop Creek volunteers - fence being taken down Sunday June 2nd 2019	Sam	

Action Items: ONGOING ITEMS

Action	Who	Completed
Terms of Reference	Kent/Sam/Kadin	Ongoing
Inquire to Village of Tahsis about bridge at Pete's Pond tributary - any plans to fix?	Sarah Fowler	Ongoing
Assess pump house ramp for Gold River egg take - take a look at LGR ramp	Kent, Roger, Kadin	Ongoing

5. Old Business:

    a. **Fisheries Stewardship Coordinator Report**

    b. **Fisheries Habitat**

    c. **Hatchery Updates**

        i. **Conuma**

        ii. **Tahsis**

        iii. **Zeballos**

    d. **Fisheries Management/Area 25 Harvest Committee Updates**

6. New Business:

7. Correspondence:

8. Financial Report:

9. Next Meeting:

10. Adjournment:

2

Nootka Sound Watershed Society
Draft Minutes
Wednesday May 29th 2019
Western Forest Products
Gold River, BC
7pm

1. Welcome and Introductions:

Attendance:

Ken Smith - GR Resident Craig Blackie - Grieg Seafood Amanda Knibbs - Tahsis Salmon Enhancement Society Barbara Malone - GR Resident Paul Kutz - Western Forest Products Joe Sinclair - Village of Gold River Sarah Fowler - Village of Tahsis	Sam Kagan - Stewardship Coordinator, NSWS Lyndy Vroom - Conuma Hatchery, DFO Gaylene Jacobson - GR Rod and Gun Club Roger Dunlop - NTC Uu-a-thluk Biologist Marcel Miner - GR Resident Kent O'Neil - President, NSWS

2. Review and adopt of the Agenda – **Motion to accept:** Amanda **2nd:** Craig
3. Review and adopt of the minutes from April 24th 2019 meeting – **Motion to accept:** Sarah **2nd:** Amanda
4. Review of action items from April 24th 2019 meeting -

Action Items: NEW ITEMS

Action	Who	Completed
Reach out to Pat and Dick Dennison re: Dunlop Creek Smolt Fence	Lyndy	Done

Action Items: ONGOING ITEMS

Action	Who	Completed
Terms of Reference	Kent/Sam/Kadin	Ongoing
Inquire to Village of Tahsis about bridge at Pete's Pond tributary - any plans to fix?	Sarah Fowler	Ongoing
Assess pump house ramp for Gold River egg take - take a look at LGR ramp	Kent, Roger, Kadin	Ongoing

5. Old Business:

   a. **Fisheries Stewardship Coordinator Report**

      1st Beach Seine in Tahsis went well - large turn out by volunteers. Caught juvenile chinook with sea lice for the first time.

      Green Crab Open House - Coming up on June12th at 10am in the Tahsis Recreation Centre.

   b. **Fisheries Habitat**

      Kent: CRF contribution agreement is still being worked out - hard work by Roger. Need to iron out last details.
      Roger: Sent off to Paul for budget amendments.
      Paul: Roger and Paul should connect to go over budget once again.

      Dunlop Creek Fence

      Ken: going well, fry counts good, smolt count OK - about 40 per trap. Should take down shortly as water levels are getting low.
      Kent: Lets aim for Sunday take down.

      ACTON: Sam contact volunteer list about Dunlop Creek take down.

   c. **Hatchery Updates**

      i. **Conuma**

         Lyndy: numbers all the same as last month. Were going to release out-plant coho tonight (29th) but changed plans - helping Tahsis instead. Likely to release out-plant coho tomorrow. Afterward the only fish left on site will be the Coho smolts. Coho clipping will happen end of July, early August.

         Kent: The Collaborative Agreement should be ready in Mid-August and the coho clipping cost will be worked in.

         Lyndy: The CA will say 150 000 coho to be clipped, but conuma is considering clipping an extra 15 000 to account for future losses.

         Lyndy: Green pens - Conuma will order the aluminum. Mikey is sewing on old netting.

         Lyndy: Burman plan: egg take from 100 pairs and keep them separate in heath trays. Will have more of the plan in place by June. Release target is 20 000.

ii. **Tahsis**

Amanda: Night releases happening tonight.
Big thank you to everybody who helped with heli-release.

Almost released all fish - less 2000 released directly into the river.
Received PSF grant for incubation upgrades around $14 000

Unexpected costs: engineered drawings. DFO unable to do it, will be external contractor (villages contractor)

Fundraising: Volunteer appreciation BBQ June 14th, Canada Day BBQ, Tahsis Days, Tahsis Days - Gently used fishing equipment yard sale (July 18th - 21st) Fishing Derby August 23rd and 24th.

Moutcha Bay Resort has created a button for guests to purchase TSES memberships, and is donating proceeds from their staff derby to the TSES.

iii. **Zeballos**

Kent: Reached out to Stacey Larson, did not hear back.

Sam: Mark Kenney wants to participate in our meetings.

Roger: Village also wants to participate, worth looking at how to conference Zeballos folk in.

d. **Fisheries Management/Area 25 Harvest Committee Updates**

Kent: did not get approval on BC SRIF EOI.
Lots of talk about DFO taking responsibility for clipping.

Roger: DFO likely planning on clipping fish at conuma.

Craig: re: acoustic tagging - was down in Victoria aquaculture conference. There was an application sent in to BC SRIF for acoustic tagging, and declined with similar feedback ie. needs to be more collaborative.

Roger: Participate in Long Live the Kings "Survive the Sound" fundraiser - sponsor a fish that is acoustically tagged and follow where it ends up.

Craig: Acoustic tagging could be a powerful project depending on the question you are asking. Could be a great fundraising tool.

6. New Business:

   Paul: WFP TFL 19 is coming up for review, the announcement will be in Wednesdays paper. Public consultation is 60 days initially. Comments from those 60 days go to the government and then into another 60 day public review/comment period.

7. Correspondence:

   Kent: $12 500 cheque from Westview Marina and Lodging - last portion of their derby contributions.

8. Financial Report:

   Kent read out the financial report. Want to highlight: $171.30 - was the cost for printed cheques, down from the estimated $500

   Motion to accept financial report: Amanda. **2nd:** Paul

9. Next Meeting:

   TBD - likely at Conuma Hatchery

10. Adjournment:

    Motion to adjourn: Craig. **2nd:** Amanda

    Adjournment at 19:50

3,

Security Clearance form – you fill out section B (make sure you have address for last 5 years to the month (ex. June 2014 to June 2019)
and section C - pg. 2 top is your name and birth date again, then initial by the 'x' for 1,2,3 and sign and date by 'x' mid page.
Instructions are on pg. 3

Also need copies of two pieces of ID – list of type provided

THESE FORMS NEED TO BE RETURNED TO CONUMA HATCHERY AND I WILL SEND TO OUR DFO SECURITY IN VANCOUVER.
You can either drop off in person or mail to;
Conuma Hatchery
PO Box 247
Tahsis BC V0P 1X0
Attn. Lyndy Vroom

Fingerprinting – depending on the RCMP detachment it will be ink or electronic.
if you do it with ink then **you** send in mail to Ottawa – address on the letter
if you do electronically then **they** will send electronically to Ottawa – important to keep your receipt and document control number that they give you for tracking purposes

If you have any further questions feel free to call or email.

Lyndy Vroom
lyndy.vroom@dfo-mpo.gc.ca
250-283-7171

Government of Canada / Gouvernement du Canada

PROTECTED (when completed)

PERSONNEL SCREENING, CONSENT AND AUTHORIZATION FORM

Reference number	Department/Organization number	File number

NOTE: For *Privacy Act* Statement refer to Section C of this form and for completion instructions refer to attached Instructions. Please typewrite or print in block letters.

A ADMINISTRATIVE INFORMATION (To be completed by the Authorized Departmental/Agency/Organizational Official)

☑ New ☐ Update ☐ Upgrade ☐ Transfer ☐ Supplemental ☐ Re-activation

The requested level of reliability/security check(s)

☑ Reliability Status ☐ Level I (CONFIDENTIAL) ☐ Level II (SECRET) ☐ Level III (TOP SECRET)

☐ Other

PARTICULARS OF APPOINTMENT/ASSIGNMENT/CONTRACT

☐ Indeterminate ☐ Term ☐ Contract ☐ Industry ☐ Other (specify secondment, assignment, etc.) Casual

Justification for security screening requirement: Employment

Position/Competition/Contract number	Title	Group/Level (Rank if applicable)
	Hatchery Labourer	GL ELE 03

Employee ID number/PRI/Rank and Service number (if applicable)	If term or contract, indicate duration period ►	From	To

Name and address of department / organization / agency	Name of official	Telephone number	Facsimile number
DFO - Conuma Hatchery	Mike Austin	(250) 283-7171	(250) 283-7171

B BIOGRAPHICAL INFORMATION (To be completed by the applicant)

Surname (Last name)	Full given names (no initials) underline or circle usual name used	Family name at birth

All other names used (i.e. Nickname)	Sex	Date of birth Y M D	Country of birth	Date of entry into Canada if born outside Canada Y M D
	☐ Male ☐ Female			

RESIDENCE (provide addresses for the last five years, starting with the most current) Home address	Daytime telephone number	E-mail address
	( )	

	Apartment number	Street number	Street name	Civic number (if applicable)	From Y M	To
1						present
	City	Province or state	Postal code	Country	Telephone number ( )	
2	Apartment number	Street number	Street name	Civic number (if applicable)	From Y M	To Y M
	City	Province or state	Postal code	Country	Telephone number ( )	

Have you previously completed a Government of Canada security screening form? ☐ Yes ☐ No

If yes, give name of employer, level and year of screening. Y

CRIMINAL CONVICTIONS IN AND OUTSIDE OF CANADA (see Instructions)

Have you ever been convicted of a criminal offence for which you have not been granted a pardon? ☐ Yes ☐ No

If yes, give details. (charge(s), name of police force, city, province/state, country and date of conviction)

Charge(s)	Name of police force	City

Province/State	Country	Date of conviction ► Y M D

Government of Canada | Gouvernement du Canada

PERSONNEL SCREENING, CONSENT AND AUTHORIZATION FORM

PROTECTED (when comple

Surname and full given names	Date of birth Y M D

C CONSENT AND VERIFICATION (To be completed by the applicant and authorized Departmental/Agency/Organizational Official)

Checks Required (See Instructions)	Applicant's initials	Name of official (print)	Official's initials	Official's Telephone numbe
1. ☑ Date of birth, address, education, professional qualifications, employment history, personal character references	✓	Mike Austin	MA.	(250) 283-7171
2. ☑ Criminal record check	X			( )
3. ☑ Credit check (financial assessment, including credit records check)	✓			( )
4. ☐ Loyalty (security assessment only)				
5. ☐ Other (specify, see instructions)				( )

The Privacy Act Statement
The information on this form is required for the purpose of providing a security screening assessment. It is collected under the authority of subsection 7(1) of the *Financial Administratio* *Act* and the Government Security Policy (GSP) of the Government of Canada, and is protected by the provisions of the *Privacy Act* in institutions that are covered by the *Privacy Act*. collection is mandatory. A refusal to provide information will lead to a review of whether the person is eligible to hold the position or perform the contract that is associated with th Personnel Screening Request. Depending on the level of security screening required, the information collected by the government institution may be disclosed to the Royal Canadia Mounted Police (RCMP) and the Canadian Security Intelligence Service (CSIS), which conduct the requisite checks and/or investigation in accordance with the GSP and to entiti outside the federal government (e.g. credit bureaus). It is used to support decisions on individuals working or applying to work through appointment, assignment or contract, transfers promotions. It may also be used in the context of updating, or reviewing for cause, the reliability status, security clearance or site access, all of which may lead to a re-assessment of th applicable type of security screening. Information collected by the government institution, and information gathered from the requisite checks and/or investigation, may be used to suppo decisions, which may lead to discipline and/or termination of employment or contractual agreements. The personal information collected is described in Standard PIB PSU 9 (Personnel Security Screening) which is used by all government agencies, except the Department of National Defence PIB DND/PPE 834 (Personnel Security Investigation File), RCM PIB CMP PPU 065 (Security/Reliability Screening Records), CSIS PIB SIS PPE 815 (Employee Security), and PWGSC PIB PWGSC PPU 015 (Personnel Clearance and Reliabili Records) used for Canadian Industry Personnel. Personal information related to security assessments is also described in the CSIS PIB SIS PPU 005 (Security Assessments/Advice).

I, the undersigned, do consent to the disclosure of the preceding information including my photograph for its subsequent verification and/or use in an investigation for th purpose of providing a security screening assessment. By consenting to the above, I acknowledge that the verification and/or use in an investigation of the precedir information may also occur when the reliability status, security clearance or site access are updated or otherwise reviewed for cause under the Government Security Polic My consent will remain valid until I no longer require a reliability status, a security clearance or a site access clearance, my employment or contract is terminated, or unti otherwise revoke my consent, in writing, to the authorized security official.

X ______________________ Signature X ______________ Date (Y/M/D)

D REVIEW (To be completed by the authorized Departmental/Agency/Organizational Official responsible for ensuring the completion of sections A, B and C)

Name and title	Telephone number
Mike Austin - Watershed Enhancement Manager	250-283-7171
Address	**Facsimile number**
PO Box 247 Tahsis, BC V0P 1X0	250-283-7171

E APPROVAL (To be completed by authorized Departmental/Agency/Organizational Security Official only)

I, the undersigned, as the authorized security official, do hereby approve the following level of screening.

Reliability Status

☐ Approved Reliability Status ☐ Not approved

Name and title

Signature Date (Y/M/D)

Security Clearance (if applicable)

☐ Level I ☐ Level II ☐ Level III ☐ Not recommended

Name and title

Signature Date (Y/M/D)

Comments

PHOTO (for Level III T.S., and/or upon request - see instructions)

INSTRUCTIONS FOR PERSONNEL SCREENING CONSENT AND AUTHORIZATION FORM TBS/SCT 330-23E (Rev. 2002/02)
Once completed, this form shall be safeguarded and handled at the level of Protected A.

General:
If space allotted in any portion is insufficient please use separate sheet using same format.

1. Section A (Administrative Information) Authorized Departmental/Agency/Organizational Official
The Official, based on instructions issued by the Departmental Security Officer, may be responsible for determining, based on five year background history, what constitutes sufficient verification of personal data, educational and professional qualifications, and employment history. References are to be limited to those provided on the application for employment or equivalent forms.

SUPPLEMENTAL INFORMATION REQUIREMENTS
Persons who presently hold a SECURITY CLEARANCE and subsequently marry, remarry or commence a common-law partnership, in addition to having to update sections of the *Security Clearance Form (TBS/SCT 330-60)*, are required to submit an original *Personnel Screening, Consent and Authorization Form*, with the following parts completed:

Part A - As set forth in each question
Part B - As set forth in each question, excluding CRIMINAL CONVICTIONS IN AND OUTSIDE OF CANADA.
Part C - Applicant's signature and date only are required

"Other". This should be used to identify if the security screening is for Site Access, NATO, SIGINT etc.

2. Section B (Biographical Information)
To be completed by the ***applicant***. If more space is required use a separate sheet of paper. Each sheet must be signed.

Country of Birth - For "NEW" requests, if born abroad of Canadian parents, please provide a copy of your Certificate of Registration of Birth Abroad. If you arrived in Canada less than five years ago, provide a copy of the Immigration Visa, Record of Landing document or a copy of passport.

- List only criminal convictions for which a pardon has NOT been granted. Include on a separate attached sheet of paper, if more than one conviction. Applicant must include those convictions outside Canada.
- Offences under the *National Defence Act* are to be included as well as convictions by courts-martial are to be recorded.

3. Section C (Consent and Verification)
A copy of Section "C" may be released to institutions to provide acknowledgement of consent.

Criminal record checks (fingerprints may be required) and credit checks are to be arranged through the Departmental Security Office or the delegated Officer.

Consent: may be given only by an applicant who has reached the age of majority, otherwise, the signature of a parent or guardian is mandatory

The age of majority is:
19 years in NFLD., N.S., N.B., B.C., Yukon, Norhwest Territories and Nunavut;
18 years in P.E.I., Que., Ont., Man., Sask. and Alta.

The applicant will provide initials in the " applicant's initials box".

The official who carried out the verification of the information will print their name, insert their initials and telephone number in the required space.
- Reliability Screening (for all types of screening identified within Section A): complete numbers 1 and 2 and 3 if applicable.
- Security Clearance (for all types of screening identified within Section A): complete numbers 1 to 4 and 5 where applicable.
- Other: number 5 is used only where prior Treasury Board of Canada Secretariat approval has been obtained.

4. Section D (Review)
To be completed by authorized Departmental/Agency/Organizational Official who is responsible for ensuring the completion of sections A to C as requested.

5. Section E (Approval)
Authorized Departmental/Agency/Organizational Security Official refers to the individuals as determined by departments, agencies, and organizations that may verify reliability information and/or approve/not approve reliability status and/or security clearances. Approved Reliability Status and Level I, II and III, as well as the signature of the authorized security official or manager are added for Government of Canada use only. Applicants are to be briefed, acknowledge, and be provided with a copy of the "Security Screening Certificate and Briefing Form (TBS/SCT 330-47)". **Note**: Private sector organizations do not have the authority to approve any level of security screening.

Photographs: Departments/Agencies/Organizations are responsible for ensuring that three colour photographs of passport size are attached to the form for the investigating agency. Maximum dimensions are 50mm x 70mm and minimum are 43mm x 54mm. The face length from chin to crown of head must be between 25mm x 35mm. The photographs must be signed by the applicant and an authorized security official. The photographs must have been taken within the last six months. It is required for new or upgrade Level III security clearances for identification of the applicant during the security screening investigation by the investigating agency. The investigating agency may in specific incidents request a photograph for a Level I or II clearances when an investigation is required.

—need copies of ID with
Security clearance application—

PROVISION OF TWO PIECES OF IDENTIFICATION

PRIMARY (Foundational)

- one of which must be a copy of
  - birth certificate, OR
  - records of immigration, OR
  - records of citizenship, OR
  - records of naturalization, OR
  - permanent resident cards.

SECONDARY (Supporting)

- another federal or provincial identification, such as a copy of:
  - passport, OR
  - certificate of Indian status, OR
  - drivers licence, OR
  - health card, OR
  - marriage certificate
  - name change originating from a jurisdictional authority

(but not departmental issued identification card).

PROVISION OF TWO PIECES OF IDENTIFICATION

PRIMARY (Foundational)

- one of which must be a copy of
    - birth certificate, OR
    - records of immigration, OR
    - records of citizenship, OR
    - records of naturalization, OR
    - permanent resident cards.

SECONDARY (Supporting)

- another federal or provincial identification, such as a copy of:
    - passport, OR
    - certificate of Indian status, OR
    - drivers licence, OR
    - health card, OR
    - marriage certificate
    - name change originating from a jurisdictional authority

(<u>but</u> not departmental issued identification card).

Fisheries and Oceans Canada | Pêches et Océans Canada

Fingerprints for Employment with the Government of Canada

Dear applicant,

As part of the security screening process your fingerprints are required. Please pay special attention to the following instructions.

You must present this letter to the person who will be taking your fingerprints. There may be a fee for this service. You must provide two pieces of identification, issued by a provincial, territorial or federal government, and at least one of which must be photographic.

Your fingerprints may be taken electronically or with ink. (See **Service Providers** below)

- If taken with ink, you must mail the fingerprints to the address below.
- If the fingerprints are taken electronically, the service provider must identify in the system that the results are sent to the address below:

  ON 80230
  Fisheries and Oceans Canada
  National Coordinator, Security
  4E163 - 200 Kent Street
  Ottawa, ON K1A 0E6

If the fingerprints are transmitted electronically, it is important that you retain your receipt and Document Control Number (DCN) for tracking purposes.

The information collected by Fisheries and Oceans Canada is in accordance with the Privacy Act Statement on your Personnel Screening, Consent and Authorization form.

Service Providers

You can have your fingerprints taken by one of the following service providers:

- **Local police service**
  Although most police centres provide this service, it is recommended that you confirm with your local police service prior to your arrival.

- **Accredited fingerprinting companies**
  To find a list of accredited fingerprinting companies, please visit: http://www.rcmp-grc.gc.ca/en/who-can-conduct-criminal-record-check.

- **DFO Personnel Security Services**
  Individuals in the National Capital Region can have their fingerprints taken at 200 Kent Street, Ottawa, ON. For an appointment, please email: Personnel_Security.XNCR@dfo-mpo.gc.ca.

Yours truly,

National Coordinator, Security
613-990-8273

Canada

Councillor Llewellyn

It has been a busy couple of weeks with events around the Village. There was the monthly Potluck at the Seniors Centre that this month was followed by an author reading...Rick James showed slides and talked about the rum running days of BC.

The next day Josie Miladinovic, the New Community Paramedic, did 2 presentations at the Seniors Centre on COPD & Congestive heart failure (CHF). These were done as requirements for her training. She will be doing more in the future.

Dan and I had our annual Deck Party and it was well attended and we received no noise complaints from our neighbours. It was a fun night.

I attended a Literacy Society meeting, we had so much to consider that we are meeting again next week.

This past Saturday I attended the grad ceremonies at CMESS. It was a well attended event and it was good to see the community celebrating these young people and their achievements.

Yesterday I attended the Connected Coast presentation put on by the SRD. While I don't understand all the numbers that get thrown around it was good to try and figure out how we get the last mile delivered. Like most in the audience the bottom line is...will it cost us more? The first half mostly went over my head...but the second half was easier to follow. I think what sticks with me is that it will probably take until 2021 before we see better connectivity here.

Respectfully submitted

Councillor Llewellyn

Fowler/Elder: VOT 335/2019

THAT the Council Reports be received. **CARRIED**

K. Bylaws

1 **2019 Tax Rate Bylaw No. 620, 2019**
Adoption

Fowler/Elder: VOT 336/2019

THAT the 2019 Tax Rate Bylaw No. 620, 2019 be received for consideration. **CARRIED**

Llewellyn/Elder: VOT 337/2019

THAT the 2019 Tax Rate Bylaw No. 620, 2019 be reconsidered , finally passed and adopted as presented this 18th day of June, 2019.

CARRIED

L. Correspondence

1 **Mike Davis, RPF, Tenures Forester, WFP Re: TFL 19 Draft Timber Supply Analysis (Link to information package below)** https://www.westernforest.com/wp-content/uploads/2017/10/TFL-19-Information-Package-v1-201905.pdf

2 **Aline Carrier, Uu-a-thluk Building Coordinator, Nuu-chah-nulth Tribal Council & Irine Polyzogopoulos, Uu-al-thluk Communications and Development Coordinator, Nuu-chah-nulth Tribal Council Re: Sponsoring a child to attend science camp.**

3 **Arjun Singh, UBCM President Re: Council's resolutions to be presented for consideration at the 2019 UBCM Convention in September.**

4 **Rebecca Bishop, Program Officer UBCM Re: 2018 CEPF Emergency Operations Centres & Training- Emergency Communications and Training Project**

5 **Rachel Blaney, MP Re: Reply from Fisheries & Oceans -regarding Chinook fishery closures.**

6 **Rachel Blaney, MP Re: Cellphone towers- Response to Petition**

Llewellyn/Elder: VOT 338/2019
THAT these correspondence items received. **CARRIED**

Fowler/Elder: VOT 339/2019
THAT all items be pulled for discussion. **CARRIED**

L1 Council requested to meet with Mike Davis regarding WFP's information package between July 2-10 (excluding July 5th).

L2 There was a brief discussion on this correspondence item and a subsequent motion made.

Fowler/Llewellyn: VOT 340/2019

THAT the Village of Tahsis donate $50 towards sending a student to camp.

2 "yes votes"

2 "no votes"

L3 Councillor Llewellyn spoke to this correspondence item. Council supports the resolution and agreed to send a letter of support to the Minister of Education.

L4 2019 UBCM Re: Requesting a meeting with Premier John Horgan or other Cabinet Ministers. Council will hold a Committee of the Whole meeting following the July 2nd regular meeting to discuss which Cabinet Ministers to seek meetings with and the topics to be discussed.

L5 There was a brief discussion on this correspondence item. CAO confirmed that a letter had been sent to Minister Wilkinson Chinook Salmon strategy.

L6 There was a brief discussion on this correspondence item.

M. New Business
None.

N. Public Input #2
A member of the public inquired into the number of OCP survey that were completed and if the data collected would be publicly available. Staff responded approximately 100-150 surveys and outlined the "next steps" which included a workshop later in the summer.
A member of the public spoke about the poor cell service on the North Island.

Rise and Report

None.

Adjournment
Llewellyn/Fowler: VOT 341/2019
THAT the meeting be adjourned at 8:23 p.m. **CARRIED**

Certified Correct this
2nd Day of July 2019.

Chief Administrative Officer

H1

VILLAGE OF TAHSIS

Report to Council

To: Mayor and Council

From: Mark Tatchell, CAO

Date: June 24, 2019

Re: Island Coastal Economic Trust (ICET) – Economic Infrastructure and Innovation Program (Stage 2) Grant Application

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PURPOSE OF REPORT:

To seek Council's consideration of this application in support of constructing Phase One of the Community Unity Trail.

OPTIONS/ALTERNATIVES

1. Approve the grant application as prepared by staff and submit it to ICET;
2. Amend the grant application;
3. Do not approve proceeding with the grant application; and
4. Any other alternative that Council deems appropriate

BACKGROUND:

On March 23, 2018, ICET approved $387,080 in funding for constructing Phase One of the Community Unity Trail. This amounts to 50% of the Phase One project budget.

The ICET Economic Infrastructure and Innovation Program grant approval process involves two steps – an initial review by the appropriate Regional Advisory Committee and the Board of Directors and a final review by the Board of Directors. This grant has been approved at the Step 1 stage.

An extension to complete the Step 2 application was granted in October 2018 to allow the Uniting 4 Communities Society to complete the *Forest and Range Practices Act* application. ICET has requested that the Step 2 application be submitted by July 12th. The application will be considered by the Board of Directors at its October 2019 meeting.

The grant application, attached to this report, includes new supporting information based on the material prepared for the FRPA application. Not included are the letters of support for the project and the detailed engineering documents prepared by Onsite Engineering Ltd. Those can be provided to Council if requested.

POLICY/LEGISLATIVE REQUIREMENTS:

1. N/A

FINANCIAL IMPLICATIONS:

As per the attached budget, the project budget is $117,000 short of the estimate funding needed to complete Phase One. Moreover, the ICET and Rural Dividend funding is contingent upon the Ministry of Forests, Lands, Natural Resource Operations and Rural Development granting the trail provincial designation and authorizing construction under FRPA.

STRATEGIC PRIORITY:

Yes.

- Improve and promote municipal trails and seek provincial statutory authorization for new trails outside of the municipal boundary

RECOMMENDATION:

Option 1 (Approve the grant application as prepared by staff and submit it to ICET)

Respectfully submitted:

Mark Tatchell, CAO

ISLAND COASTAL ECONOMIC TRUST

PROGRAM APPLICATION

ECONOMIC INFRASTRUCTURE & INNOVATION PROGRAM | STAGE TWO

For ICET funding requests over $50,000.

SECTION 1 – PROJECT NAME

Please select a project name that captures the essence of your project.

COMMUNITY UNITY TRAIL CONSTRUCTION (PHASE ONE)

SECTION 2 - APPLICANT INFORMATION

APPLICANT INFORMATION

Name of Organization:	Village of Tahsis		
Street Address or PO Box:	PO Box 219		
City/Town/Village:	Tahsis	Postal Code:	V0P 1X0
Phone:	250 934-6344	Fax:	250 934-6622
Email:	reception@villageoftahsis.com		
Incorporation/Business/Society Number:			

DESIGNATED OFFICER (SIGNING AUTHORITY)

Officer's Name:	Mark Tatchell		
Title:	Chief Administrative Officer		
Street Address or PO Box:	PO Box 219		
City/Town/Village:	Tahsis	Postal Code:	V0P 1X0
Phone:	250 934-6344	Fax:	250 934-6622
Email:	mtatchell@villageoftahsis.com		

PRIMARY CONTACT (IF DIFFERENT FROM DESIGNATED OFFICER)

Name & Title:			
Street Address or PO Box:			
City/Town/Village:		Postal Code:	
Phone:		Fax:	
Email:			

SECTION 3 – PROJECT INFORMATION

1. EXECUTIVE SUMMARY

This project will construct the initial 11 km of multi-phase, multi-purpose trail from the Tahsis trailhead to the headwaters of the Little Zeballos River. When fully constructed, the 25 km trail will link Tahsis to Zeballos and the First Nation community of Ehatis. The project is a joint venture by the Villages of Tahsis and Zeballos and the Mowachaht/Muchalaht and Ehattesaht/Chinehkint First Nations. This application seeks $387,080 which represents 50% of the total budget. A Rural Dividend contingent grant of $200,000 has been awarded. The remaining $187,080 (24%) will be contributed by the Villages of Tahsis and Zeballos and the Mowachaht/Muchalaht First Nation and the Ehattesaht/Chinehkint First Nation as well as additional fund raising from the Rural Dividend program and the private sector. The overall project is expected to generate up to $546,000 annually for the first three years in new tourism revenue for the region, contributing to the regional economy, spurring new businesses and job creation.

2. INVESTMENT/SECTOR AREA

Specify which area of investment/sector you are applying under.

- ☐ Industry and Business Support
- ☐ Downtown Revitalization
- ☐ Strategic Tourism Infrastructure
- ☒ Destination Trails
- ☐ Innovation Infrastructure

3. PROJECT RATIONALE

Explain what issue or opportunity your project addresses and why this is important to your community and/or region?

The economy of the Nootka Sound region has exhibited trends common in small remote formerly forestry or fishing dependent communities across British Columbia. The population of Tahsis was 1351 in 1970, 607 in 2001 and is now 248 according to the 2016 census. Zeballos recorded 232 residents in 1996, 189 in 2006 and 107 in 2016, a decline of over 50% in 20 years. Population trends for the First Nations partners are not available.

Between 1972 and 1998, average household income in the region was higher than the Provincial average. Since contractions in the forest and fishing sectors in the early 2000s, the average household income has fallen below the average.

The reasons for the decline in population and household income are: 1) the shrinking of the forest industry from 1980 to the closure of two sawmills in the region by 2003 and 2) shrinkage in the size of the commercial fishing fleets in Tahsis and Zeballos. Moreover, while there are still logging operations within the Nootka Sound region, Tahsis and Zeballos in particular see little direct benefit.

To combat the declining populations caused by the loss of resource-based employment, the Village of Zeballos (2014) and Tahsis (2015) completed Economic Development Strategies (attached). Both contain several actions aimed at increasing the appeal of the community for tourism and new resident attraction and both identify trail development as an action priority. The Community Unity Trail ("CUT") is a multi-community effort involving these two municipalities and two First Nations (Mowachaht/Muchalaht and Ehattesaht/Chinehkint) to retain businesses and residents as well as stimulating the regional tourism economy.

The regional tourism economy needs a larger flow of visitors in order to be sustainable, meaning it can support basic visitor services for most of the year. This region experiences its greatest tourist influx during the May-September period when the sport fishing is most active. Quad/ATV riding season begins earlier in the year and ends later. By establishing a tourism product and service in the "shoulder" seasons the Community Unity Trail creates new market revenue.

The wilderness beauty of the north west coast of Vancouver Island – mountains, ocean, fjords, beaches, wildlife, forests, caves and karst, waterfalls – is a natural tourism draw. This trail offers an accessible means of enjoying this diverse and breathtaking environment.

This trail project utilizes existing assets built for resource extraction, Forest Service Roads, for recreational and eco-tourism opportunities. This re-purposing or multi-purposing of resource roads potentially offers new opportunities to Tahsis, Zeballos, Ehatis and other communities on the North Island by opening up Crown lands for tourism services and products.

Although the Mowachaht/Muchalaht and Ehattesaht/Chinehkint have rich history and culture, there is limited information denoting their presence and informing visitors and residents about these two Nations. Through signage the trail will celebrate the history and contributions of these nations thus providing a platform for these two Nations to communicate important facts to a broader audience which is an important facet in advancing Reconciliation

4. PROJECT DESCRIPTION

Provide a detailed description of the project and the objectives and outcomes. Please attach all relevant project design and engineering documents or other information that will help clarify project objectives.

The Community Unity Trail is a multi-phase, multi-use recreational trail connecting the Villages of Tahsis and Zeballos and the First Nation community of Ehatis. Having completed the engineering work and environmental assessments and having submitting the recreational trail application under the *Forest and Range Practices Act*, this grant application seeks funding for the construction of the first section from the trail head in Tahsis to the Little Zeballos River headwaters. Most of the fully completed trail utilizes two deactivated forest service roads (FSRs). New trail construction is needed to link the two FSRs, which is entailed in this first phase. The procurement and construction including trail head infrastructure and signage in Indigenous languages for the first section is included in this application.

This initial 11 km section of the trail climbs from Tahsis toward Extravagant Creek offering viewpoints of the Tahsis Inlet toward Nootka Sound. The summit elevation is 670 meters (2200 feet). From that point there are commanding views of the steep and stunning fjord which runs due south toward the Sound, Nootka Island to the west and Mt. Conuma to the east. Nootka Island is home to Friendly Cove or Yuquot where Captain Cook first arrived in 1778 and later Captain Vancouver in the 1790s. This area, including Tahsis, has been the territory of the Mowachaht/Muchalaht First Nation for over 2,000 years.

After crossing Extravagant Creek, the trail passes the ethereal Coral Caves which are easily entered and explored on foot. The trail then winds through majestic old growth forest and eventually descends by properly engineered switchbacks to the headwaters of the Little Zeballos River.

The second and final section of the trail (not included in this application) follows the Little Zeballos River to Zeballos crossing several streams, some fish bearing with runs of Coho and chum salmon. There are many late season angling opportunities along this section of the trail. Closer to Zeballos, a spur trail will be constructed along Bingo Creek leading to a wide estuary on the Zeballos Inlet. This will become a day use or campground area when this section is constructed. The trail ends in the heart of Zeballos allowing easy access to food, fuel and lodging for trail users.

The trail will be constructed to primarily accommodate all-terrain vehicles/quads and off-road motorcycles (dual sport), but mountain bikers and hikers may also use the trail.

A comprehensive (over 300 page) application under the *Forest and Range Practices Act* ("FRPA") to have the trail designated under s. 57 of the Act as a provincial recreation site was submitted to FrontCounter BC in March 2019. As of this date, Ministry of Forests, Lands, Natural Resource Operations and Rural Development Recreation Sites and Trails staff have responded to the application written seeking additional information which is being gathered by the project team. Ministry staff have attended trail planning meetings and have been briefed on the proposed trail construction plan and future operational plans as it pertains to the statutory application process. Onsite Engineering Ltd. prepared the FRPA application using LiDAR data to show the trail design, bridge crossings and environmental aspects.

5. PROJECT ACTIVITIES

Describe the specific activities that the project funding will be used for. This should relate directly to the key budget categories.

1. Project manager contractor/hired.
2. Competitive procurement for construction contractor
3. Bridge and trail engineering reviews.
4. Procurement and construction of 2 new bridges and 3 new bridge abutments

5. Agreement with partnering First Nations on historical and cultural information to be posted at the Tahsis trailhead and other locations. Agreement with partnering First Nations on Indigenous languages on trail signs.
6. Procurement and construction of Tahsis trailhead infrastructure, picnic tables, kiosks (with First Nations history and culture information), rain shelter, gates.
7. Brushing, pullback, cross ditching and culvert clean outs on the Extravagant mainline.
8. Upgrading Extravagant main stream crossings.
9. Constructing new trail section from Extravagant mainline to the Little Zeballos mainline.
10. Establishing terms and conditions of use for this first phase of the trail.

6. PROJECT TIMELINES

Estimated Project Start Date: January 6, 2020

Estimated Project Completion Date: September 30, 2020

Implementation Plan:
Provide a detailed timeline which specifies when key milestones will be achieved.

ALL DATES ARE IN 2020

March 2	Tender issued for project construction, including trail construction and trailhead infrastructure
March 23	Evaluation of bids completed and contract awarded
April 6,	Pre-construction meeting
April 20	Mowachaht/Muchalaht First Nation and Ehattesaht/Chinehkint First Nation confirm locations of cultural and historical importance and content, e.g., culturally modified trees, and the design of signs with their respective languages
April 27	Brushing, ditching and culvert cleanouts of Extravagant Main completed
May 15	Bridge construction completed
July 31	Construction of new linking trail section completed
August 31	Trailhead construction (picnic tables, kiosks, rain shelter and locking bollards) and parking area completed
September 15	Operating policy and procedures completed
September 30	Official opening

7. ALIGNMENT WITH ECONOMIC DEVELOPMENT PRIORITIES

Explain how your project aligns with local, regional, provincial or industry economic development priorities and strategies. Please refer to specific strategic documents.

The project will increase economic development and resilience by enhancing the region's appeal to tourists and amenity migrants. Nootka Sound region offers high calibre outdoor recreation experiences in a pristine environment that is relatively accessible (compared to Haida Gwaii or the Great Bear Rainforest, for example). Tahsis and Zeballos/Ehatis offer a range of adventure and recreation activities on land and water. Both communities are actively engaged in marine tourism marketing and support sport fishing promotion and activities. The CUT reinforces the existing nucleus of tourism products and experiences and, importantly, attracts a new market segment that will also make use of other outdoor recreation products. The project contributes to the diversity and critical mass that is required to make the region a sustainable tourism destination.

Community and regional resilience depends on stopping the outflow of residents and attracting new full-time residents. There is a substantial body of research that shows that for small communities that are rich in natural amenities, tourism is the primary source of attracting new residents. A demographic movement named amenity migration refers to the movement of people from urban areas to rural communities where the motivation is the quality of natural amenities and a perceived better quality of life. Additions to recreational opportunities increase the likelihood that potential amenity migrants will visit and that they will choose to relocate.

The Ministry of Transportation and Infrastructure completed a multi-million-dollar upgrade to the Head Bay Forest Service Road in 2018 in recognition that safe reliable transportation corridors are fundamental to economic development. Telus is committed to providing cell phone service by fall 2019 and the Connected Coast will deliver fibre optic to support broadband internet by 2021.

Based on a Business Case Analysis (which was undertaken with support from ICET), the anticipated annual increment in tourism revenue from the trail is $546,000. This is a significant revenue stream for a region with fewer than 1200 residents. Importantly, the revenue will be shared across the region (as described in two sections down). It is enough of an injection for small businesses to add services or products, extend their hours or extend their seasons. The motorized segment is a three-season opportunity, extending what is for many tourist-oriented businesses a short season tied to sport fishing.

Tahsis has a 2015 Economic Development Strategy (attached). Section 3.2 notes the need for partnerships, including with other communities and First Nations. The project supports that goal by creating a partnership among two local governments and two First Nations.

Section 1.2 aligns the Strategy with the economic development policies of the Village's Official Community Plan, including business retention and diversification, resident attraction, working in partnerships and favouring development that is ecologically sustainable. The project contributes to those objectives.

Tourism is one of five Sector Themes. Section 4.4 recommends several actions that would improve the Village's appeal to visitors: village beautification, support for investment in visitor accommodations, clean up of mill sites, waterfront asset improvement and transportation improvements.

Strategy 13 is directed to tourism development. It calls for support in the development of new trails, events and facilities. It recommends packaging of tourism opportunities in order to increase appeal.

The 2014 Economic Development Strategy for Zeballos observes on page 10:
Communities throughout the province are recognizing the opportunities associated with recreational trail users as a source of much needed tourism revenues and drivers of economic development for rural communities and urban centres alike.

Consequently, among its economic development priorities:
Tourism recreational infrastructure: The focus of the conversation on tourism infrastructure was on trails in the region that would help to attract visitors for mountain biking, hiking and potentially some motorized recreation. There was also recognition that the trails would support other community goals as well, including those related to health, recreation and social wellbeing.

8. PROJECT BENEFITS

Estimated temporary jobs (during construction/implementation):
Estimated Temporary jobs: 4.0 FTEs (1800 hour basis) – 2.5 semi-skilled, 1.0 skilled and 1.0 professional
Estimated direct permanent jobs (once project is complete): Once the complete 25 km length of trail is constructed and operational, the trail will generate at minimum 2 FTEs in operations and maintenance year round and up to 4 seasonal positions responsible for trail operations, maintenance and security.

Incremental Economic Benefits:

Detail all new, incremental economic benefits to the community and/or region.

The most recent and rigorous study on ATV tourism spending is a 2015 Oregon study (Lindberg, K. and Bertone-Riggs, T. 2015. Oregon Off-Highway Vehicle (OHV) Participation and Priorities. Salem, OR: Oregon Parks and Recreation Department.). That study had a large sample and used rigorous statistical analysis. Average per person spending on non-local, multi-day trips was $120 USD or about $150 CDN. The largest expenditures were gas (34%), food (26%), restaurants (13%), campground (9%) and motel (5%). More than half of the total spending of ATV riders in the state occurred in a single coastal region (one of eleven regions) that is well populated with travel amenities. Spending in remote regions was in the order of half of the state average. ATV riders spend considerable amounts on hospitality amenities – mainly food and alcohol but also sometimes lodging. As noted elsewhere, they are capable of being self-reliant taking food, fuel and water they need with them and camping. The Oregon study found that riders also have interests in fishing charters, whale watching and eco-tours in the region, which mirrors the other types of tourism opportunities in the Nootka Sound region.

The Business Case Analysis concluded that once the entire trail is completed the annual number of riders for the first three years would be 910. Based on the Oregon study, a two-night stay would amount to $600.00 in spending for 2 people. This would generate $546,000 in new tourism revenue for the region. In addition, ATV tourists would potentially take advantage of the other outdoor recreational tourism opportunities such as fishing charters, kayaking, diving and eco-tours generating indirect economic benefits.

Once the trail is operational, more and better data could be collected from visitors and/or operators regarding the number of ATV visitors and spending.

Increasing the overall number of annual visitors would also create demand for other services and businesses. As noted elsewhere, the Mowachaht/Muchalaht First Nation have expressed an initial interest in developing a campground and staging area on their reserve lands in Tahsis.

9. PERFORMANCE MEASUREMENT

Describe how you intend to measure success in achieving project benefits. Identify baseline indicators that will be used to measure the success of your project.

Project objective:

Construction of 11km of the initial section of the trail

Performance indicator:

Construction completed according to specifications and on time and on budget.

Project objective:

This section of the trail evidences environmental values and aesthetic qualities.

Performance indicator:

Survey of trail users to gather their opinions and assessment of the trail.

Project objective:

Increasing the awareness and understanding by trail users of the history, culture and languages of the partnering First Nations.

Performance indicator:

Trail signage describing the history, noting culturally significant sections of the trail and using Indigenous languages on trail markers.

Project objective:

Establishment of trail operations organization led by First Nations partners.

Performance indicator:

Financial, human resources, legal, policies and procedures, training, and equipment aspects fully addressed and implemented.

10. COMMUNITY CONSULTATION AND SUPPORT

Detail any consultation processes undertaken and detail community/regional support and partnerships (please attach letters of support).

The project involves two incorporated municipalities and two First Nations. The name, Community Unity Trail, embodies the cooperation of the four partner communities and their appreciation of their shared economic futures.

The trail traverses the traditional territories of the Mowachaht/Muchalaht First Nation and Ehattesaht/Chinehkint First Nation. The participation of these First Nations in the CUT partnership signals a substantial commitment to work collectively for shared prosperity. The project will create economic opportunities for all four partners. For the Mowachaht/Muchalaht, there is the potential for developing reserve lands on the Tahsis Inlet as a campground, parking area and retail for ATV/Quad riders and other trail users. For both First Nations, there are opportunities for their members to provide cultural tours as well as being employed in the trail construction and on-going trail management and maintenance.

The experience of working together will strengthen relationships among the four communities. Inevitably, by working together on a tourism venture, skills will be shared. The quality of the project (trail, hospitality, and culture) will be shaped by the contributions of the partners and their communities.

The four communities have joined together to incorporate a non-profit society – the Uniting 4 Communities Society – which is the legal entity which will be responsible for trail governance and management. The Society has 8 directors – 2 from each community – selected by the communities. The society held its second annual general meeting in Zeballos on May 24, 2019.

Finally, this local government and First Nations integrated economic development project could serve as a model of joined up planning and development.

Letters of support from the two First Nations are attached.

The ATVBC, the provincial ATV and Quad riders organization, has been involved with the project and supports it, as do the Campbell River ATV and Comox Valley ATV clubs.

A letter of support from Gerald Whalley, Electoral Area "A" director is also attached.

The Village of Tahsis council adopted an Off Road Vehicle bylaw in 2018 to support and regulate the use of Off Road Vehicles on all municipal roads within the Village. All roads within the Village are part of the designated trail under the bylaw.

11. ORGANIZATION CAPACITY

Organization Profile

Describe your organization and its primary mandate. Attach a copy of your latest annual report.

The Village of Tahsis is a municipal government established by Letters Patent in 1970. Like all municipal governments, its mandate is set out in the *Community Charter* and the *Local Government Act*. A copy of the 2018 Annual Report is attached.

Project Management

Please indicate how the project will be managed and who the management team will be.

The four communities will establish a project steering committee to provide oversight and governance for the project. The steering committee will recruit a project manager with experience and skills in trail construction. Although the project manager will under contract to the Village, he/she will functionally report to the project steering committee. The project manager will be responsible for overall project management – scope, schedule, budget - and the delivery of all aspects of the project. The project manager will report to the steering committee who, in turn, will communicate to the four communities and other stakeholders.

Organization expertise

Please detail your organization's previous experience with similar projects and/or technical capacity and expertise to manage the project.

Over the past three years the Village has managed over $4 million in capital projects (roads, water, sanitary and storm) funded through grants from senior levels of government. The projects completed in 2017 and 2018 were completed on time and budget and met the terms and conditions of the funding agreements. Moreover, the projects resulted in improved public services through asset repair and renewal. In addition, the Village has completed multiple program specific projects also funded externally. The Village has a very competent management team with major project experience at the local and provincial government level. Moreover, the Village has a comprehensive procurement policy which incorporates best practices as well as strong financial internal controls. As noted above, the intention is to recruit a skilled project manager for this project rather than manage the project internally.

Financial Capacity

Indicate how your organization will finance project costs pending reimbursement. Attach a copy of your most recent financial statements.

The Village will either fund the project from internally (e.g., reserves) or obtain short-term borrowing from the Municipal Finance Authority to manage cash flow in order to meet progress billings, for example. The Village has experience obtaining short term borrowing from the MFA. The Village's director of finance is a CPA who has experience with capital project financial management.

12. PROJECT SUSTAINABILITY

Describe how the facility or project will be sustainable in the long term (structure of operations, revenue streams, expenses, ongoing maintenance, capital upgrades etc.). Please attach relevant projected cashflow statements.

The Uniting 4 Communities Society constitution states:

To develop and manage community based, shared use trail system in the "Tahsis-Zeballos Mowachaht/Muchalaht First Nation-Ehattesaht/Chinehkint First Nation Region" in order to offer trail-based tourism products that will maximize economic development opportunities for the region in an environmentally responsible manner.

Going forward, the society will assume the governance and management responsibilities for the trail as the Forest and Range Practices Act application has been made by the society. A trail management plan has been developed (attached) and the society is also expected to prepare a trail sustainability plan.

As noted in the trail management plan, it is expected that the one or both of the First Nations will use the trail as an opportunity for job training and creation. Fund raising will need to continue from grants and from the private sector once the entire trail is constructed.

13. MARKET ASSESSMENT AND COMPETITIVE IMPACT

Describe all target markets the project is seeking to serve. Identify any issues related to competition with other organizations or businesses or impacts on adjacent communities or region.

The analysis of competitiveness was undertaken as part of the business case analysis. The following was based on conversations in 2016 with representatives of 26 ATV clubs in British Columbia and Alberta and from the OHV associations in those provinces and Washington state.

The most important factors in the appeal of a riding area are:

The ideal situation is nearby Crown land containing logging roads and trails. On Vancouver Island, the privately held lands that were once part of the Esquimalt & Nanaimo Railway are an obstacle for riders. Riders are excluded and cut off from Crown land. Riders look for areas they can use and there are not many dedicated motorized or even multi-purpose trails on the Island. Therefore, competition is low on Vancouver Island, making this trail appealing to Vancouver Island riders.

The Powell River/Sunshine Coast region and Lower Mainland/Fraser Valley region have limited accessible trail areas. Generally, riders travel into the near Interior for riding. The CUT competes with the limited local trails and with the Nicola, Similkameen, Thompson Rivers and Okanagan Valleys, which have abundant riding opportunities. The CUT is competitive with these regions, on the basis of proximity and accessibility.

Across the rest of BC accessible trails on Crown Land are abundant. Respondents from most clubs said they have high-quality riding areas in their "backyard." When riders seek new terrain, they have a wide choice of regions within a relatively short radius. Competition, on the basis of riding options, is high in the rest of BC.

The situation in most of Alberta is similar to the BC Interior: competition is high. However, there are very few places to ride in Washington State, so competition is low.

Abundance and variety of trails are the cardinal virtues for ATV riders. Circular routes or loops off main trails are valued. A variety of terrain, viewpoints and destinations (lakes, summits, communities, historical sites) are valued. Three-metre-wide trails are optimal.

The pattern of competitiveness for trail attributes aligns with the proximity and accessibility. Vancouver Island and the coastal regions have only a few areas with enough trails to occupy a rider for several days. However, ATV clubs on Vancouver Island are attempting to create an extensive trail network using forest service roads which would ultimately establish hundreds of kilometers for trails traversing the North Island.

Unique riding conditions are appealing. High elevation trails, trails along waterways or seashore, through sand dunes, canyons and old growth forest are examples. Competitiveness (appeal) of the CUT will be increased by routing it to take advantage of the unique features of a west coast Vancouver Island experience, routing the trail to "destinations" and providing basic trails amenities such as signs, picnic tables and ocean-side campground.

Like most tourists, motor sport recreationists want to sample the local hospitality and culture. They have a range of tastes in accommodation and quality of dining. Many like to participate in other forms of outdoor recreation and some are interested in the history of places they visit. The most likely age cohort to travel is over 55 years. ATV club members, the most likely riders to travel with their machines, have a median age of about 60 years. The types of activities they participate in is limited by their age. Many of them ride quads because they no longer have the mobility for hiking.

Without going through the geographic regions, it can be said that the CUT region has a smaller range of amenities compared to other regions. The relative lack of amenities available means that the CUT partner communities will work among themselves and with the business community to utilize existing tourism products and to develop products that appeal to motorized tourists.

Psychological appeal plays a large role in where tourists decide to go. The CUT product competes well, and contrary to tangible factors, is more competitive in the distant geographic regions on the basis of evocative and emotive motivators (EEM).

The CUT product's most compelling EEM are the seaside experience, rainforest experience, new frontier caché and end-of-the-road caché. Vancouver Island and mainland coast riders will be somewhat compelled by these motivators. Riders from the Fraser Valley, rest of BC and Alberta will be strongly compelled by these motivators.

Because there are fewer options on Vancouver Island, Island riders will be drawn to ride the CUT and, even more so, if it connects them with other trails. Riders from the south coast, Lower Mainland and Fraser Valley, who already frequently travel with ATVs, may be less likely to be drawn, but some will come. With so many extensive areas to choose from in the Interior, where lengthy circuits and ample amenities are available, CUT does not compete as well against riding experiences in the rest of BC. It does compete well with Washington State. It is the EEM motivators that will compel riders to visit.

MARKETING AND COMMUNICATIONS PLAN

Describe how you will market your project/facility in the short term and long term to ensure optimal results. Describe how you will acknowledge ICET's contribution and those of your other funders.

Until the entire trail is constructed, marketing will be limited to communicating the status of the project with stakeholders, including ATV clubs and similar groups. Once the trail is constructed, it is expected that the society will promote the trail nationally and internationally on social media sites, and various club websites. ICET, the Province of BC and any other funders will be acknowledged on all public communication.

14. RISKS

Describe the risks related to the project and how you will address them (ie: cost overruns, obtaining tenure, obtaining matching funding, changes to the economy etc.). List any approvals and permits required to complete the project.

Risk: MFLNRORD could reject the *Forest and Range Practices Act* (FRPA) application for trail designation and construction authorization
Mitigation: Municipal staff and engineers are responding to questions from Ministry staff arising from the FRPA application. It is expected that the approval process will be iterative as the Ministry works through the technical, statutory and policy consideration.

Risk: MFLNRORD could reject Rural Dividend funding application
Mitigation: MFLNRORD has advised that once the FRPA approval is granted, that the project can apply for further Rural Dividend grants. At the 2018 UBCM conference Minister Donaldson's staff advised the Village of Tahsis delegation that the provincial government supports this project and wants the trail to be constructed.

Risk: Cost overruns for construction
Mitigation: A 20% contingency has been added by the applicant to the construction estimate.

Risk: A statutory right of way cannot be negotiated with one or more private property owner
Mitigation: While not the preferred solution, the municipalities can exercise their right to expropriate.

15. FUNDING AND BUDGET

Please download and complete the Funding and Budget Excel workbook.

SUPPORTING DOCUMENTATION

- ☐ Completed Funding and Budget Worksheet
- ☐ Organization's latest financial statement (audited if available)
- ☐ Organization's annual report
- ☐ Formal letter(s) of support (recommended)

SUBMISSION

Application Form and all supporting documents should be submitted electronically, by email to info@islandcoastaltrust.ca

Please do not submit hard copies of the application by mail or fax.

TRAIL PROJECTS MUST COMLETE SCHEDULE A
DOWNTOWN REVITALIZATION PROJECTS MUST COMPLETE SCHEDULE B

AUTHORIZATION

I/we certify that the information provided in this Application Form is to the best of my/our knowledge, complete, true and accurate and the proposal including plans and budgets is fairly presented.

I/we authorize the Island Coastal Economic Trust to make any enquiries of persons, firms, corporations, federal and provincial government agencies/departments and non-profit organizations operating in our organization's field of activities, to collect and share information with them, as Island Coastal Economic Trust deems necessary, in order to reach a decision on this application, to administer and monitor the implementation of the project and to evaluate results after project completion.

I/we agree that the information provided in this application form will be shared with the appropriate Regional Advisory Committee and Island Coastal Economic Trust staff and consultants.

I understand that the information in this application may be accessible under the Freedom of Information Act (FOI).

I/we also understand that all Trust correspondence, relative to our Application, must be kept confidential and that any breach whatsoever of confidentiality will immediately result in the annulment of the Application.

I/we also understand that ICET will not be responsible for any costs incurred in the preparation of this application, or any subsequent application for funding from the Trust, and this application is being prepared entirely at my/our own risk and cost.

Signature of Authorized Representative(s):	
Printed Name(s):	
Title(s):	
Date:	

SCHEDULE A – DESTINATION TRAIL PROJECTS

If you are requesting funding for a trail project, please complete the following section.

1. PROMOTE TOURISM ATTRACTION AND INCREMENTAL ECONOMIC BENEFITS

Describe the potential to attract new tourism to the area, retain tourism for longer periods or provide incremental economic benefits to area businesses and communities.

The business case analysis concluded that tourism in smaller communities on North Vancouver Island is in decline due to decline in population. There are fewer hospitality and other services available to attract tourists than before. In the estimates of the number of riders who will visit the CUT, the detrimental impact of few services on market appeal is noted. Nootka Sound has a modest market recognition as a remote, pristine adventure tourism and fishing destination. Name recognition is valued in brand development and marketing messages.

The Village's economic development strategy recommends several strategies that would improve the Village's appeal to visitors: village beautification, support for investment in visitor accommodations, clean up of mill sites, waterfront asset improvement and transportation improvements. Strategy 13 is directed to tourism. It calls for support in the development of new trails, events and facilities. It recommends packaging of tourism opportunities in order to increase appeal. Current tourism resources are meagre. The positive side is that there are ample unexploited tourism development opportunities.

The CUT is part of a vision for an extensive network of trails in the North Island. The CUT is a necessary step toward creating the larger system and benefitting from the volume of visitors that will be attracted to an extensive, managed trail system.

It is a challenge for small communities to develop and market their tourism assets. Small steps toward diversification are likely the only route, aside from investment attraction. The CUT is an addition to the product array of the region. The development of tourism product is synergic. Every addition to the product spurs development across the sector. The CUT is one piece in the development of tourism in the region. It will draw visitors who participate in the other forms of outdoor recreation currently offered. Nature-based and marine tourism are just two other markets that should be developed alongside motorized trail tourism.

CUT is a regional initiative. Even without the trail, it makes very good sense for these communities to market collectively. They are then marketing a sizeable array of tourism experiences with, presumably, a shared budget.

For the incremental economic benefit, see the response to Question 8.

2. SIGNIFICANCE OF TRAIL

Describe the significance of the trail and its ability to gain international, national or provincial recognition.

The Island Coastal Economic Trust ATV Research Report prepared in 2016 for this project lists primary components of an ATV trail: the people, the route, the trail, the experience, the diversity of riders and the quality of supporting infrastructure. These six characteristics are based upon primary research conducted by the Quad Riders ATV Association of British Columbia.

The trail will become known based on the volume of riders (and the riders who report or share their experience), the experiences of those riders and marketing efforts by the society. The following considerations suggest that the trail is well positioned to gain extensive recognition.

- There are a significant numbers of ATV users on Vancouver Island and in British Columbia.
- There is a lack of ATV recreation locations on Vancouver Island and throughout coastal British Columbia.
- ATV users are high earners who are willing to travel to recreate.
- As a target market, ATV users may be more resilient to high ferry costs than other tourist groups because of the lack of comparable ATV related infrastructure, the high-cost of ATVing in general and because of the higher than average annual income of ATV users.
- The region has an existing network of active and inactive logging roads that are used by groups of ATV riders and could serve as a basis for additional trail development.
- The region offers varying terrain, the additional recreational opportunities (fishing, hiking, camping, etc.) and the potential for the beautiful views that ATV users indicate as being important factors in a high-quality riding experience.
- There are existing groups of ATV users and ATV clubs who are passionate about developing the North Island into an ATV recreation destination.
- The recent completion of the Pye Mountain ATV Recreation Site demonstrates the commitment and capacity of regional ATV clubs, while also offering the unique opportunity to create a cluster of ATV riding locations on the North Island.
- The CUT could attract large numbers of off-Island tourists during the high season, while attracting Vancouver Island based ATV users on weekends.
- Despite the remoteness of the trail and the absence of an active ATV organization in the communities, regional ATV organizations have stated their support of the project and their belief that a properly designed and managed trail will be a success. Moreover, this trail could leverage existing points of interest and develop camping infrastructure to improve the trail and encourage longer visitor stays and a larger, more diverse target market.

3. COLLABORATIVE PLANNING

Describe how the planning process includes engagement and fosters collaboration with key stakeholders.

The planning for this project began in November 2015 and has continued over the past almost 4 years. Villages of Zeballos and Tahsis Councils, the Mowachaht/Muchalaht and Ehattesaht/ Chinehkint First Nations have established a supportive, respectful and extremely positive working relationship which has continued as the communities have worked through issues regarding the implications of this trail on the territories of the two First Nations.

From the beginning other key stakeholders have been businesses such as Western Forest Products and BC Hydro; Campbell River ATV Club and ATV BC/Quad Riders Association; Island Coastal Economic Trust representative; the former Ministry of Jobs, Tourism and Skills Training (now Ministry of Forests, Lands, Natural Resource Operations and Rural Development) representatives have all participated in the planning meetings in various capacities.

In preparing the FRPA application, the society directors (2 from each community) were directly involved in preparing the Trail Operational Management Plan (which is attached).

The society structure (constitution and bylaws) will foster on-going collaborative planning as the society takes on increasing responsibility for the trail management and governance.

4. VALUE FOR COST

Provide an accurate assessment of all trail costs including a breakdown per metre.

The full project cost for this initial section of 11 km is $774,160 which equates to $70.38 per metre. Although most of this initial section utilizes the existing FSR, the 700 metres of new trail section linking the Extravagant Main to the Little Zeballos Main traverses a very steep, wet and unstable slope which will require special construction. Of the entire 25km of the full trail, this is the most challenging and capital intensive sections but it is also the critical "missing link" connecting the two FSRs. On the Extravagant main, minor repairs are required on steeper sections and upgrades are required for stream crossings. This section of the trail offers excellent views of the Tahsis inlet and provides access to the Coral Caves. The environmental assessment of the new linking trail section found no "at-risk" plants, wildlife or ecosystems. There is wildlife evidence – Roosevelt Elk corridor, bear dens and salmon in the Little Zeballos River. This linking section also winds through spectacular old growth forest, which is a shrinking and valuable wilderness attraction.

5. QUALITY ACCESS POINT

Describe in detail the trail access point and its location with respect to communities or key tourism assets. Describe existing or planned parking for public use.

The Tahsis trailhead will be in an existing parking area which is located immediately adjacent to the trail. The parking area also has easy walking path access to the Tahsis Inlet shore. The parking area is patrolled and serviced by the Village. There are pit toilets and garbage cans. A restaurant, drinking water tap, sani-flush station, RV Park and Campground and additional parking are located 500m from the trailhead. A Rec Sites campground is located 6 km from the trailhead. The Mowachaht/Muchalaht First Nation have expressed interest in developing a campground on their reserve lands which are located 4 km from the trailhead along the Tahsis Inlet. If developed, this campground would be close to other services, namely, fuel, grocery store, liquor store, restaurant, hardware store, and the recreation centre.

6. SUSTAINABLE MAINTENANCE AND MANAGEMENT STRATEGY

Describe how ongoing trail maintenance will be managed and funded on a long-term basis.

The society is expected to seek funding for the second and final phase of construction of this trail. Moreover, the society is expected to seek federal (e.g., Indigenous and Northern Affairs Canada) and provincial funding to support employment training for Aboriginal youth for on-going trail maintenance and operations. The society is also expected to research, develop and implement a trail sustainability plan with accompanying policies and procedures.

Until the society is financial sustainable, the communities will support it and the trail project. The details on the trail operations, including maintenance, are described in the Trail Operational Management Plan (attached).

7. SECURED LAND TENURE AND REGULATORY APPROVALS

Indicate if land tenure and required regulatory and environmental approvals have been secured, and if not, describe the process undertaken thus far.

The Extravagant mainline is a current FSR under road permit to Western Forest Products, Inc. Although there are no current harvesting plans, WFP has advised that at some future date there will be industrial activity on the north end of the FSR near the new trail section. WFP supports the development of the Community Unity Trail and has committed to operating to minimize impact on trail users (see emails from WFP representatives). A MOU with WFP will be secured to clarify the FSR/trail sharing on the Extravagant mainline.

A Memorandum of Understanding with WFP will be prepared concurrent with the trail construction.

Approximately 750m of the trail within Tahsis crosses private property. The Village is authorized in law to hold a statutory right of way and Covenant under the *Land Title Act*. Negotiations with the property owner are close to concluding. An appraiser has been retained by the Village to conduct an appraisal so the financial aspect of the negotiations can be settled.

A Public Trail Statutory Right of Way/Covenant has been prepared by the Village's solicitor and will be presented to the landowner in February 2018.

8. STRATEGIC MARKETING PROGRAM

Describe how the trail project addresses the issue of trail marketing and include a plan to market the trail in collaboration with local, regional and provincial tourism destination marketing organizations or other relevant organizations.

The targeted market for the trail is primarily ATV/Quad and trail bike riders in BC, Alberta and Washington State. Riders worldwide may learn about the trail through web presence and social media. Vancouver Island is the most prolific market but surveys indicate that promotion in the lower mainland, Alberta and Washington State will be rewarded. The marketing strategies for all regions will be similar but more intensive in the most promising markets. The key characteristics of the ATV/Quad and trail bike rider market are:

1. Mainly over 55 years with most frequent travellers at post-retirement age
2. Slightly above average annual household income for BC
3. Range of amenity requirements: some camp; others seek comfort rewards after a day's ride
4. Riders also participate in other activities – fishing, hunting and geocaching
5. Length of touring vacation varies
6. Highly social – enjoy events and end of day socializing
7. Obtain travel information from club websites and word of mouth events

Marketing channels will be social media, website, ATV club newsletters and earned media. ATVBC staff have attended planning meetings and the Campbell River ATV club has actively participated in meetings and supported the project. Project representatives from the Village and Mowachaht/Muchalaht First Nation delivered a presentation at the Quad Riders/ATVBC Spring 2018 F2F meeting in Campbell River. This is important because the most effective marketing channel is direct to consumer. The Quad Rider/ATV world is highly social. Riders meet at poker runs, jamborees, AGMs and a host of other informal events. There are 42 ATV clubs listed on the provincial association website. Most of the clubs have websites with latest news columns and/or newsletters received by members. Some clubs use Facebook instead of a website. The Alberta and Washington State Associations are willing to post notices. Three Alberta clubs have been contacted and they are willing to post notices as well.

SCHEDULE B – DOWNTOWN REVITALIZATION PROJECTS

Please complete this section if you are applying for a downtown revitalization project. Please review the Economic Infrastructure Program Guidelines Appendix C prior to completing this section.

1. ECONOMIC VITALITY

Describe how your project activities will result in a more attractive and usable Downtown commercial space while retaining and strengthening existing Downtown businesses, attracting new economic activity into the Downtown, and diversifying the business mix. Please detail any complementary incentive programs or investment.

2. PROFESSIONAL DESIGN

Describe how your design integrates the unique physical, cultural, or historic assets of the community.

3. MARKETING AND PROMOTION

Describe how your marketing plan will promote the Downtown as a focal point of community life, a unique, appealing shopping environment, and as a viable and attractive location for business investment.

4. ORGANIZATION AND COMMUNITY INVOLVEMENT

Describe how the project will engage the community in the initiative and build long-term, collaborative relationships that are essential to sustainable Downtown renewal.

5. RESULTS WITHIN THREE TO FIVE YEARS

Describe how you plan to measure progress related to your downtown economy. If possible, please provide baseline information (pre-project condition) and the anticipated results within three to five years.

6. INVOLVEMENT OF BUSINESS COMMUNITY

Describe how the local business community will be involved in the project.

Island Coastal

TRUST

Economic Infrastructure Program
Stage 1 - Funding and Budget

Applicant: Village of Tahsis

Project Name: Community Unity Trail Construction (Phase 1)

Sources of Funding	Cash	In Kind	Confirmed Yes/No	Percent of Total
Applicant's Equity (if applicant is a local government use row below)	$ -	$ -		0.0%
Local government (specify below):				
Village of Tahsis	$ 20,000.00	$ 10,000.00	YES	
Village of Zeballos	$ 20,000.00	$ -	YES	3.0%
Federal Funding Sources (specify below):				
	$ -	$ -		0.0%
	$ -	$ -		0.0%
Provincial Government Funding Sources (specify below):				
Rural Dividend (4th intake)	$ 200,000.00	$ -	NO	30.4%
	$ -	$ -		0.0%
Private Sector Contributions (specify below):				
	$ -	$ -		0.0%
	$ -	$ -		0.0%
Other sources of funding (specify below):				
Mowachaht/Muchalaht First Nation	$ 10,000.00	$ -	YES	1.5%
Ehatessaht/Chnehkint FN	$ 10,000.00	$ -		1.5%
Request from Island Coastal Economic Trust	$ 387,080.00	$ -	NO	58.9%
Subtotal	$ 647,080.00	$ 10,000.00		**95%**
Grand Total	$ 657,080.00			

Project Budget (define categories)	$ Amount
Construction contractor equipment, salary and wages - trail construction	$ 430,188.00
Consulting and Professional fees	$ 43,452.00
Capital and supplies (bridges and trailhead infrastructure)	$ 190,000.00
Infrastructure related costs - bridge and trailhead infrastructure construction	$ 110,520.00
	$ -
	$ -
	$ -
Total Project Budget	**$ 774,160.00**

H2

MFABC
Municipal Finance Authority of BC
CLIENT PROFILE

SCHEDULE OF AUTHORIZED SIGNERS

Please fill out this form electronically. You will need Adobe Acrobat Reader, which can be downloaded free of charge from Adobe.com. If you are unable to download the free program, please contact us. Submit completed forms to: mfa@mfa.bc.ca

Organization Legal Name Village of Tahsis

Address 977 South Maquinna Drive, Tahsis BC V0P 1X0

Contact Name Deborah Bodnar **Contact Email** dbodnar@villageoftahsis.cor

Effective Date July 2, 2019

Step 1: Signing authority structure – choose only one

- (●) Any one signer from list
- ( ) Any two signers from list
- ( ) Two signers – one from List A and one from List B

Step 3: Programs – the signers below will be authorized to sign on the following programs – chose any/all that apply
If you will be having separate sets of signers for separate programs, please submit a new Signing Structure for each program.

- ☑ Equipment Financing
- ☑ Short-Term Borrowing
- ☑ Long-Term Borrowing
- ☑ Pooled Investment Funds
- ☐ All Programs *(except PHISA)*

Part 3: List of Authorized Signers
Please note these names may differ from your authorized PHISA Program signers. The undersigned is a complete and current list of designated signing officers with Municipal Finance Authority:

LIST A – First Name Last Name and Job Title	LIST B – First Name Last Name and Job Title
Martin Davis, Mayor	
Sarah Fowler, Deputy Mayor	
Mark Tatchell, CAO	

Signing Authority - Organization's General Instructions

Organization (Payor) Legal Name:	Village of Tahsis
Effective Date:	January 15, 2016
Signing Authority Structure:	(i) Any one Signer from list ☑
	(ii) Any two Signers from list ☐
	(iii) Two Signers-one from List "A" and one from List "B" ☐

Organization's Signing Lists (if applicable):

LIST "A"	LIST "B"
Jude Schooner Randy Taylor Mark Tatchell	

L1

Mark Tatchell

From:	Waddell, Lisa <Lisa.Waddell@bchydro.com>
Sent:	Friday, June 14, 2019 6:16 PM
To:	Mayor Davis
Cc:	Mark Tatchell
Subject:	BC Hydro Invitation to meet at 2019 UBCM Convention
Attachments:	UBCM 2019 BC Hydro Meeting Request Form.docx

BC Hydro
Power smart

June 14, 2019

Mayor Martin Davis
Village of Tahsis

Dear Mayor Davis and Council:

BC Hydro is pleased to be participating in the upcoming 2019 UBCM Convention in Vancouver during the week of September 23-27, 2019.

If you would like to arrange a meeting on a local issue with one of our senior managers while you are at the convention, please fill out the attached form and return it with your email request to Lisa Waddell (lisa.waddell@bchydro.com) by **Friday, July 26h**. We may not be able to accommodate meeting requests received after this date.

Meetings will be scheduled for September 24-26. We will provide full details when we confirm your meeting date and time.

If you have any questions, please don't hesitate to contact me at 250-755-7180 (office) or 250-618-6267 (cell).

We look forward to seeing you at the convention.

Sincerely,

T. Olyf

Ted Olynyk
Community Relations Manager
Vancouver Island-Sunshine Coast

BC Hydro
Power smart

UBCM 2019 Meeting Request with BC Hydro

Municipality:
Attendees:
Topic: (Please pose as a question):
Background:
Key Contact:

LC

Administration
Box 3333 | 6250 Hammond Bay Road
Nanaimo, BC Canada V9R 5N3
t: 250.758.4697 f: 250.758.2482
e: info@virl.bc.ca w: www.virl.bc.ca

June 14, 2019

Mr. Mark Tatchell
Chief Administrative Officer
Village of Tahsis
PO Box 219,
Tahsis, BC, V0P 1X0

Dear Mr. Tatchell,

RE: Proposed Tahsis Branch

The proposed site for the Tahsis branch was presented to the Vancouver Island Regional Library (VIRL) Board in January of 2018. Preliminary site investigations and other planning work was initiated, including a site survey, environmental assessment and geotechnical analysis.

The geotechnical engineer engaged by VIRL noted that there is unsuitable fill in that area, consisting of wood waste (sawdust and/or "hog fuel"). Wood waste fill is not suitable for supporting building foundations, so that site is not considered feasible without significant investment in site preparation.

This information was presented verbally at the September 2018 meeting, and the decision to not proceed with that site was supported by the Board. This was communicated to the Tahsis CAO shortly after, and confirmed at our meeting with him in November 2018. This decision was included in the facilities report as part of the agenda for the January 2019 meeting, including the decision to not proceed.

Sincerely,

Rosemary Bonanno

Rosemary Bonanno, BA MLS
Executive Director

CC: Vancouver Island Regional Library Board of Trustees
Executive Leadership Group
Divisional Manager, Executive Director's Office

L3

Janet St. Denis

Subject: FW: Hydro

From: Trevena.MLA, Claire <Claire.Trevena.MLA@leg.bc.ca>
Sent: June 13, 2019 11:45 AM
To: Reception Account <Reception@villageoftahsis.com>
Subject: Hydro

Dear Mayor Davis

I know that you have been concerned about 2 tier billing and its impact on peopled in our communities who have no choice but to use hydro. I have been lobbying on this for a number of years and I am pleased that this policy is now being reviewed.

If you would like to get involved in future rate designs I would suggest you check out https://www.bcuc.com.

Regards,

Hon. Claire Trevena, MLA
North Island

L4

HOUSE OF COMMONS
CHAMBRE DES COMMUNES
CANADA

Rachel Blaney
Member of Parliament
North Island-Powell River

Ottawa ON
June 4, 2019

The Honourable Jonathan Wilkinson
Minister for Fisheries, Oceans and the Canadian Coast Guard
House of Commons
Ottawa, ON
K1A 0A6

RE: Chinook Fisheries – Post-Announcement Consultation Report

Dear Minister,

Following the announcement on chinook fishery restrictions on April 16 of this year, I reached out to my constituents requesting information on how this impacted them. I received hundreds of responses and these responses are summarized in the report included with this letter.

I hope you take the time to review the report closely and consider the effects that these restrictions have, particularly in my riding where the fishing and fishing-related tourism industries are some of the most economically vital.

The final section of the report contains detailed requests from my office to yours. I would appreciate a comprehensive response to each point raised by the end of July 2019.

Regarding the invitation to the riding, my staff and I would be happy to assist in making that a reality. North Island – Powell River is geographically vast, but I believe most affected people in these industries would agree to meeting in a somewhat central location, such as Campbell River.

I understand that you are busy but anticipate that eight weeks is sufficient to respond, and a day-trip to one of the regions most affected by these restrictions is not too much to ask.

Ottawa
318 Confederation Building
House of Commons
Tel.613.992.2503

Campbell River Office
908 Island Highway
Campbell River, BC V9W 4B2
Tel. 250.287.9388
Toll free: 1 (800) 667.8404

Powell River Office
4697 Marine Avenue
Powell River, BC V8A 2L2
Tel. 604.489.2286

Rachel.Blaney@parl.gc.ca

House of Commons
Chambre des communes
Canada
Rachel Blaney
Member of Parliament
North Island-Powell River

Sincerely,

Rachel Blaney, MP
North Island-Powell River

Ottawa
318 Confederation Building
House of Commons
Tel.613.992.2503

Campbell River Office
908 Island Highway
Campbell River, BC V9W 4B2
Tel. 250.287.9388
Toll free: 1 (800) 667.8404

Powell River Office
4697 Marine Avenue
Powell River, BC V8A 2L2
Tel. 604.489.2286

Rachel.Blaney@parl.gc.ca

CHINOOK PUBLIC FISHERY RESTRICTIONS

Impact on the federal riding of North Island – Powell River

4 June 2019

"The chinook public fishery restrictions have had devastating effects on this riding that the minister does not seem to understand. That is why I wanted to reach out to people in this and related industries and ask how they were affected. I received hundreds of emails, letters, phone calls, drop-ins and messages, and I want to thank everyone who took the time to do so.

I know this is not going to be an easy time for anyone involved. Businesses and individuals are already feeling the impact. I want everyone to know that I will not let this go; I will keep pushing the minister to ensure that we have thriving salmon and communities." MP Rachel Blaney

Summary

Even with hundreds of submissions received there was consensus on many points and the impacts are similar regardless of where people are located. It was said consistently that no one cares more about having a healthy salmon population than those who rely on them for their livelihood. This speaks to the economic hardship that people are facing and their desire to support sustainable fisheries now and for years to come.

The primary concerns in the correspondence received can be broken down into five sections: the economic impact of the decisions, the impression of the Ministry, the timing and tone of the announcement, the consultations conducted, and conservation measures.

Economic Impact

The economic impact of the decision to restrict chinook retention cannot be overstated. We heard from charters, guides, outfitters, and lodges that, on average, they will be experiencing a 50% decrease in revenue this year. The effects, to a lesser degree, will be felt by the tourism industry. Hotels, restaurants, transportation and recreational entertainment providers are expecting a decrease in traffic. Both the fishing and tourism industries will be hiring less, and in some cases no seasonal staff this year, and some will have no choice but to lay off current staff.

The trickle-down effect throughout local economies, while not as readily visible, is another major concern.

There is a lack of understanding at the federal level of the realities in smaller coastal communities. In major urban centres slashing an industry can hurt, but most people can find employment in other industries. For the communities in the riding of North Island – Powell River that is not the case. Fisheries are the lifeblood of most economies, and any abrupt closures or restrictions leave people with few or no other options when it comes to supporting themselves and their families. This difference needs to be recognized by the minister and department, and taken into consideration as part of their decision-making process.

Impression of Ministry

The effects these decisions made in Ottawa have on coastal communities directly impacts the overall impression of the Ministry of Fisheries, Oceans, and the Canadian Coast Guard. It was stated repeatedly that there is no faith remaining in the ministry to simultaneously manage existing ocean wildlife stocks and the fishing economy. This was also reflected in comments regarding the timing and consultation process.

As highlighted in yellow in the attached infographic from Fisheries and Oceans Canada, the stocks of concern in the restrictions are caught so little in North Island – Powell River management areas that the decision to restrict the fishery in the area is largely considered to be political and not science-based.

Many people are concerned about chronic underfunding and understaffing of the Department of Fisheries and Oceans in the area to fulfill their mandate of managing scientific, conservation and enforcement measures. There is concern that the new restrictions on chinook retention will essentially be unenforceable in such a vast management area with so few staff, resulting in poaching activities.

Timing and Tone of Announcement

The restrictions were announced on April 16, 2019 even though the chinook fishery officially opened on April 1. There was some indication in the preceding months that the ministry may be creating measures to improve Fraser River chinook survival rates, and three options were rumored to be on the table.

Some respondents said the knowing earlier would not have made a significant difference in the impact on their livelihoods, but most said earlier notice would have saved them some financial hardship and/or stress.

Outfitters and other recreational suppliers began stocking inventory as early as September 2018, and they are now stuck with large inventories that they don't anticipate being able to sell. Guides, charters, and lodges began taking bookings as early as last fall, but most began filling their spaces in January of this year. They are now struggling to cancel or rebook domestic and international clients.

The tone of the announcement was also criticized. Many people had the impression that fisheries had been closed entirely. Several respondents suggested that these media releases be accompanied with clear language about which fisheries are still open to encourage tourism and fishing activities.

Being notified by the end of 2018 would have allowed businesses to adjust for inventory and booking changes. Chambers of commerce and communities at large would have been able to alter their marketing toward different fisheries or other tourism experiences such as whale and bear watching, mitigating the economic impacts if the announcement had been more clear and thought-out.

Consultations

Overall impression of the consultations conducted regarding chinook restrictions were negative, although for different reasons. Some respondents were not made aware that the consultations were taking place at all, and others were only notified at the last minute and thus unable to attend. The consultation period was also described as being too short.

Those that did attend consultation meetings with department officials stated that they felt like a decision had been made before the consultation process even began, that their concerns were heard but summarily ignored, and that the process was being carried out as an exercise in box-ticking.

Conservation Measures

The majority of respondents stated that adequate conservation measures have been missing for decades, current measures are underfunded, and/or that there are measures that should be taken now to ensure thriving salmon populations.

Habitat degradation was a primary concern and its restoration and enhancement, a major priority. Restoration projects will take years to have a significant impact, which many respondents said is why they should be prioritized now. Support for hatcheries was also mentioned as a way to preserve wild salmon stocks and ensure that Southern Resident Killer Whales and other local mammals have adequate food.

Two conservation measures not currently in place were suggested by many respondents. The first, to begin adipose fin clipping of hatchery salmon which would lead to the institution of a mark-selective fishery in a few years, allowing wild stocks the opportunity to return in greater numbers to their spawning streams without negatively impacting the fishing economy. The second was to reinstate the pinniped harvest.

Next Steps

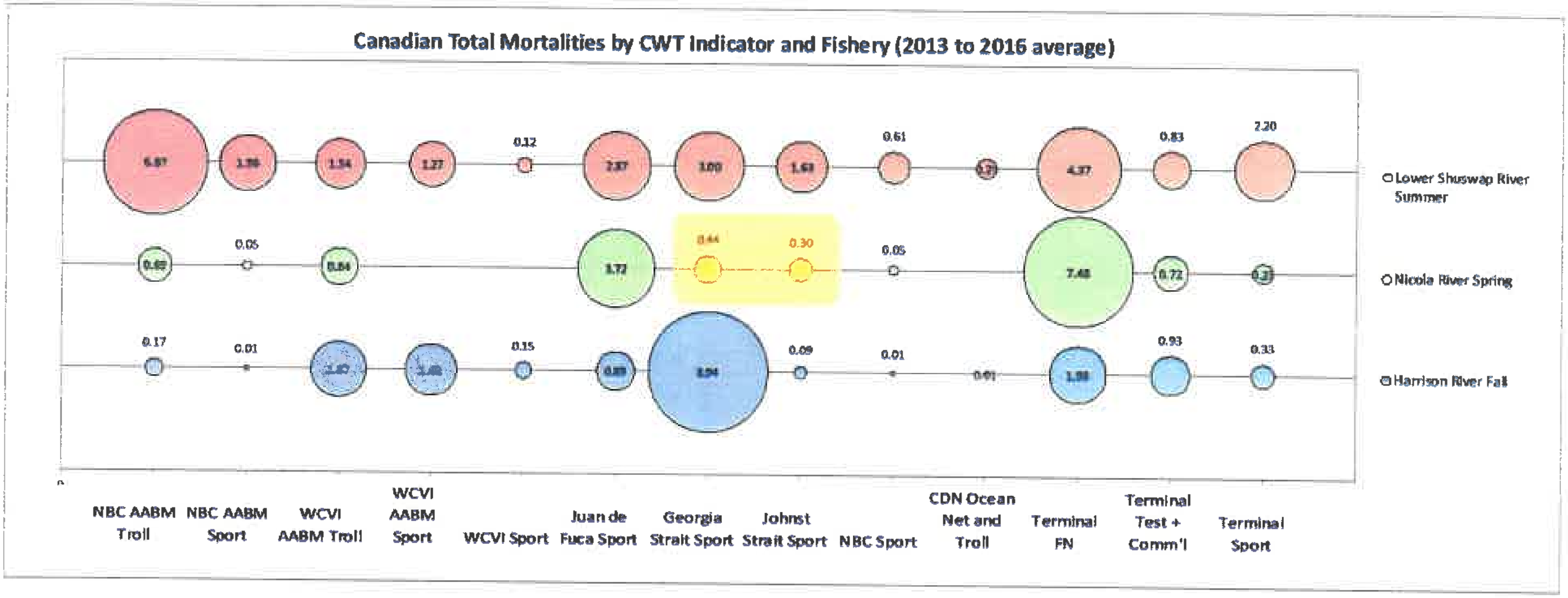
As part of this report, Rachel requests that the minister take the following actions:

1. Promptly provide a comprehensive response, addressing all concerns outlined in this report; including a specific response to the graph at the end of this report justifying the closures of Chinook public fisheries in the highlighted areas given their low catch rate
2. Create a bold, comprehensive and fully-funded action plan to support Pacific fisheries
3. Commit to getting more DFO staff on the ground and in the water as soon as possible
4. Visit the riding of North Island - Powell River and speak to people affected by these measures before the end of summer 2019
5. Release the funding for the BC Salmon Innovation and Restoration Fund as soon as possible
6. Purchase the necessary equipment for salmon hatcheries to begin adipose fin-clipping and implement a mark-selective fishery as soon as possible

"Please allow me to again express my gratitude to everyone who was able to take the time to respond. Ottawa needs to know how their decisions affect the people on the coast who live to fish and fish to live, and that it is these people who care more than anyone else about the health of wild Pacific salmon.

My job is to protect both the economy and ecology of North Island – Powell River, and I take great pride in representing people such as yourselves who help me accomplish all that and more." MP Rachel Blaney

Annex 6



Retrieved from: Department of Fisheries and Oceans (Feb 5, 2019), *2019 Chinook Management Approach Letter*

L5

BRITISH
COLUMBIA

ARCS: 292-30
File: FNR-2018-86859

June 14, 2019

Sent via email: mtatchell@villageoftahsis.com

Mark Tatchell
Village of Tahsis
977 South Maquinna Drive
PO Box 219
Tahsis BC V0P 1X0

Dear Mark Tatchell:

Re: Request for Access to Records
***Freedom of Information and Protection of Privacy Act* (FOIPPA)**

I am writing further to your request received by the Ministry of Forests, Lands, Natural Resource Operations and Rural Development. You narrowed your request on February 27, 2019 through conversations with the ministry and emails with Juliane Letawske, Senior FOI Analyst. Your request is for:

Any notices or other records filed, including investigations issued, against Western Forest Products Inc. and WFP's logging contractors or sub-contractors for failure to perform an obligation under a license, agreement, or legislation and WFP's non-compliance or the noncompliance of any of WFP's logging contractors or sub-contractors working within Tree Farm License 19 with those obligations. (Date Range for Record Search: From 01/01/2013 To 10/02/2018)

Please find enclosed a copy of the records located in response to your request. Some information has been withheld pursuant to section(s) 15 (Disclosure harmful to law enforcement) and 22 (Disclosure harmful to personal privacy) of FOIPPA. A complete copy of FOIPPA is available online at:

http://www.bclaws.ca/civix/document/id/complete/statreg/96165_00

Your file is now closed.

.../2

Ministry of Citizens' Services Information Access Operations

Mailing Address:
PO Box 9569 Stn Prov Govt
Victoria BC V8W 9K1

Website:
www.gov.bc.ca/freedomofinformation
Telephone: 250 387-1321
Fax: 250 387-9843

These records will be published on the BC Government's Open Information website a minimum of ten business days after release. To find out more about Open Information, please access the Open Information website at: www.gov.bc.ca/openinformation

If you have any questions regarding your request, please contact Juliane Letawske, the analyst assigned to your request, at 250 387-0915. This number can be reached toll-free by calling from Vancouver, 604 660-2421, or from elsewhere in BC, 1 800 663-7867 and asking to be transferred to 250 387-0915.

You have the right to ask the Information and Privacy Commissioner to review this decision. I have enclosed information on the review and complaint process.

Sincerely,

Juliane Letawske, Senior FOI Analyst
On behalf of Meghan Kane, Manager
Resource Team, Information Access Operations

Enclosures

How to Request a Review with the
Office of the Information and Privacy Commissioner

If you have any questions regarding your request please contact the analyst assigned to your file. The analyst's name and telephone number are listed in the attached letter.

Pursuant to section 52 of the *Freedom of Information and Protection of Privacy Act* (FOIPPA), you may ask the Office of the Information and Privacy Commissioner to review any decision, act, or failure to act with regard to your request under FOIPPA.

Please note that you have 30 business days to file your review with the Office of the Information and Privacy Commissioner. In order to request a review please write to:

Information and Privacy Commissioner
PO Box 9038 Stn Prov Govt
4th Floor, 947 Fort Street
Victoria BC V8W 9A4
Telephone 250 387-5629 Fax 250 387-1696

If you request a review, please provide the Commissioner's Office with:

1. A copy of your original request;
2. A copy of our response; and
3. The reasons or grounds upon which you are requesting the review.

INSPECTION REPORT

RECORD ID: 000020
IDIR s.15
02:47 Mar 19, 2019

Natural Resource Officer: IDIR s.15	**Region:** West Coast **Field Unit:** Campbell River	**Date of Inspection:** March 20, 2014
Client: WESTERN FOREST PRODUCTS INC., WEST ISLAND TIMBERLANDS	**In Attendance:**	**Compliance Status:** Compliant

Client Contact Information:
WEST ISLAND REGION,_118 - 1334 ISLAND HIGHWAY,

CAMPBELL RIVER,BC,CANADA
V9W8C9

Latitude: 49.4816

Longitude: -126.3016

Location Description:
Head Bay R06864 Sucwoa M/L

Primary Tenure/Authorization:
R06864/FTA

Secondary Tenure/Authorization:

Alleged Non-Compliance Summary:

aNC#	Estimated Incident Date	Parent Act	Act/Regulation	Section	Description	Action Taken

Warning Ticket #:

ERA Case #:

Description and Comments:

Natural Resource Officer: [IDIR's.15

Signature: X

I certify that this inspection conforms to Ministry compliance

Sent to:
WEST ISLAND REGION,_118 - 1334 ISLAND HIGHWAY,

CAMPBELL RIVER,BC,CANADA
V9W8C9

Attachments and Comments:	**Delivered via:** Email: ☐ Fax: ☐ Mail: ☐ Registered Mail: ☐ Hand Delivery: ☐

INSPECTION REPORT

RECORD ID: 000024
IDIR s.15
08:45 Apr 02, 2014

Natural Resource Officer: Paul Sackney

Region: West Coast
Field Unit: Campbell River

Date of Inspection: Mar 20, 2014

Client:
WESTERN FOREST PRODUCTS INC., WEST ISLAND TIMBERLANDS

In Attendance:

Compliance Status:
Compliant

Client Contact Information:
WEST ISLAND REGION,_118 - 1334 ISLAND HIGHWAY,

CAMPBELL RIVER,BC,CANADA
V9W8C9

Latitude:
49.4614

Longitude:
-126.2954

Location Description:
Hisnit M/L

Primary Tenure/Authorization:
R06864/FTA

Secondary Tenure/Authorization:

Alleged Non-Compliance Summary:

aNC#	Estimated Incident Date	Parent Act	Act/Regulation	Section	Description	Action Taken

Warning Ticket:

ERA Case #:

Description and Comments:

Natural Resource Officer: [Paul Sackney]

Signature: X

I certify that this inspection conforms to Ministry compliance procedures.

Sent to:
WEST ISLAND REGION,_118 - 1334 ISLAND HIGHWAY,

CAMPBELL RIVER,BC,CANADA
V9W8C9

Attachments and Comments:	**Delivered via:** Email: ☐ Fax: ☐ Mail: ☐ Hand Delivery: ☐

INSPECTION REPORT

RECORD ID: 005899
IDIR s.15
02:43 Mar 19, 2019

Natural Resource Officer: IDIR s.15

Region: West Coast
Field Unit: Campbell River

Date of Inspection: September 23, 2014

Client: WESTERN FOREST PRODUCTS INC., WEST ISLAND TIMBERLANDS

In Attendance:

Compliance Status: Compliant

Client Contact Information:
WEST ISLAND REGION,_118 - 1334 ISLAND HIGHWAY,

CAMPBELL RIVER,BC,CANADA
V9W8C9

Latitude: 50.036114

Longitude: -126.757175

Location Description:
TFL19 CP: 440 BLK: L515

Primary Tenure/Authorization:
tfl19/FTA

Secondary Tenure/Authorization:

Alleged Non-Compliance Summary:

aNC#	Estimated Incident Date	Parent Act	Act/Regulation	Section	Description	Action Taken

Warning Ticket #:

ERA Case #:

Description and Comments:

Block is yarded to roadside. Block in-active at this time. Roads to and within block are all good. Metal culvert present at the S2 road crossing. Inflow side of the culvert is a S5 stream not far from the crossing (steep incline).

Natural Resource Officer: [IDIF s.15

Signature: X

I certify that this inspection conforms to Ministry compliance

Sent to:
WEST ISLAND REGION,_118 - 1334 ISLAND HIGHWAY,

CAMPBELL RIVER,BC,CANADA
V9W8C9

Attachments and Comments:	Delivered via: Email: ☐ Fax: ☐ Mail: ☐ Registered Mail: ☐ Hand Delivery: ☐

INSPECTION REPORT

RECORD ID: 008419
IDIR s.15
02:39 Mar 19, 2019

Natural Resource Officer: IDIR s.15	**Region:** West Coast **Field Unit:** Campbell River	**Date of Inspection:** November 28, 2014

Client: WESTERN FOREST PRODUCTS INC., CORPORATE OFFICE	**In Attendance:**	**Compliance Status:** Compliant

Client Contact Information:
_118 - 1334 ISLAND HIGHWAY,,
CAMPBELL RIVER,BC,CANADA
V9W8C9

Latitude: 50.13857

Longitude: -126.81425

Location Description:
TFL19 CP:441 BLK: X-62

Primary Tenure/Authorization:
tfl19/FTA

Secondary Tenure/Authorization:

Alleged Non-Compliance Summary:

aNC#	Estimated Incident Date	Parent Act	Act/Regulation	Section	Description	Action Taken

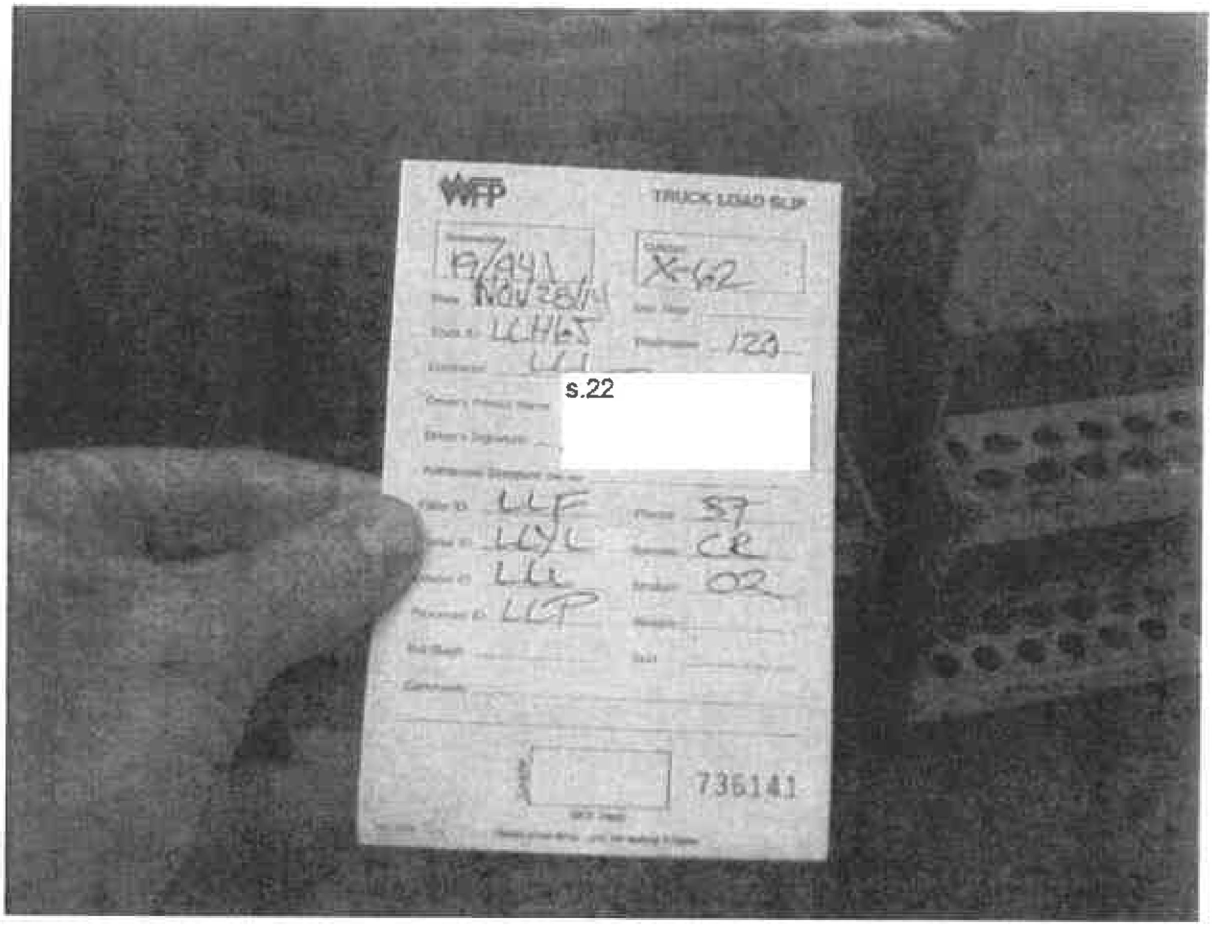
Warning Ticket #:

ERA Case #:

Description and Comments:
TMTR Inspection of a truck from block X-62. All is good. Load slip complete and load was well marked. Side markings present.

Natural Resource Officer: [IDIR s.15 Signature: X I certify that this inspection conforms to Ministry compliance	**Sent to:** _118 - 1334 ISLAND HIGHWAY,, CAMPBELL RIVER,BC,CANADA V9W8C9

Attachments and Comments:	Delivered via:
1) Load slip.JPG TMTR Load Slip. 2) Truck.JPG Truck hauling timber.	Email: ☐ Fax: ☐ Mail: ☐ Registered Mail: ☐ Hand Delivery: ☒



Img : Load slip.JPG

Img : Truck.JPG

INSPECTION REPORT

RECORD ID: 037747
IDIR s.15
09:34 Sep 27, 2016

Natural Resource Officer: Adam Vojnic	**Region:** West Coast **Field Unit:** Campbell River	**Date of Inspection:** Jul 21, 2016
Client: Western Forest Products Inc. Gold River	**In Attendance:** Levi Bauder, Elliot Molsberry, Daniel Smallacombe	**Compliance Status:** Alleged Non-Compliance

Client Contact Information:
300 Western Dr
Gold River, BC
V0P 1G0

Latitude: 49.4521

Longitude: -126.2112

Location Description:
Nesook Bay, Western Forest Products, Gold River Site

Primary Tenure/Authorization:
TFL19/FTA

Secondary Tenure/Authorization:

Alleged Non-Compliance Summary:

aNC#	Estimated Incident Date	Parent Act	Act/Regulation	Section	Description	Action Taken
2375	Jul 21, 2016	Forest Act	Forest Act	84 (3)	Fail to conspicuously timber mark, unscaled timber being stored or transported	Warning Ticket #
3291	Jul 21, 2016	Forest Act	Timber Marking & Transportation Regulation (FA)	10 (2)	Documentation requirements: Inadequate transport description	Enforcement Action

Warning Ticket:
8654

ERA Case #:
34723

Description and Comments:

July.21, 2016 - Nesook Bay, Western Forest Products TFL19 Boom Inspection

An inspection was conducted on boom NK0NS16-00-21 by the C&E Branch, Ministry of Forest, Lands and Natural Resource Operations at Nesook Bay.

The inspection revealed Bundle Tag# 366450 contained timber which was hammer marked with both Timber Mark: 19/355 & 19/348.
Bundle Tag # 366450 did have all bundle cable intact and no loose timber was observed.

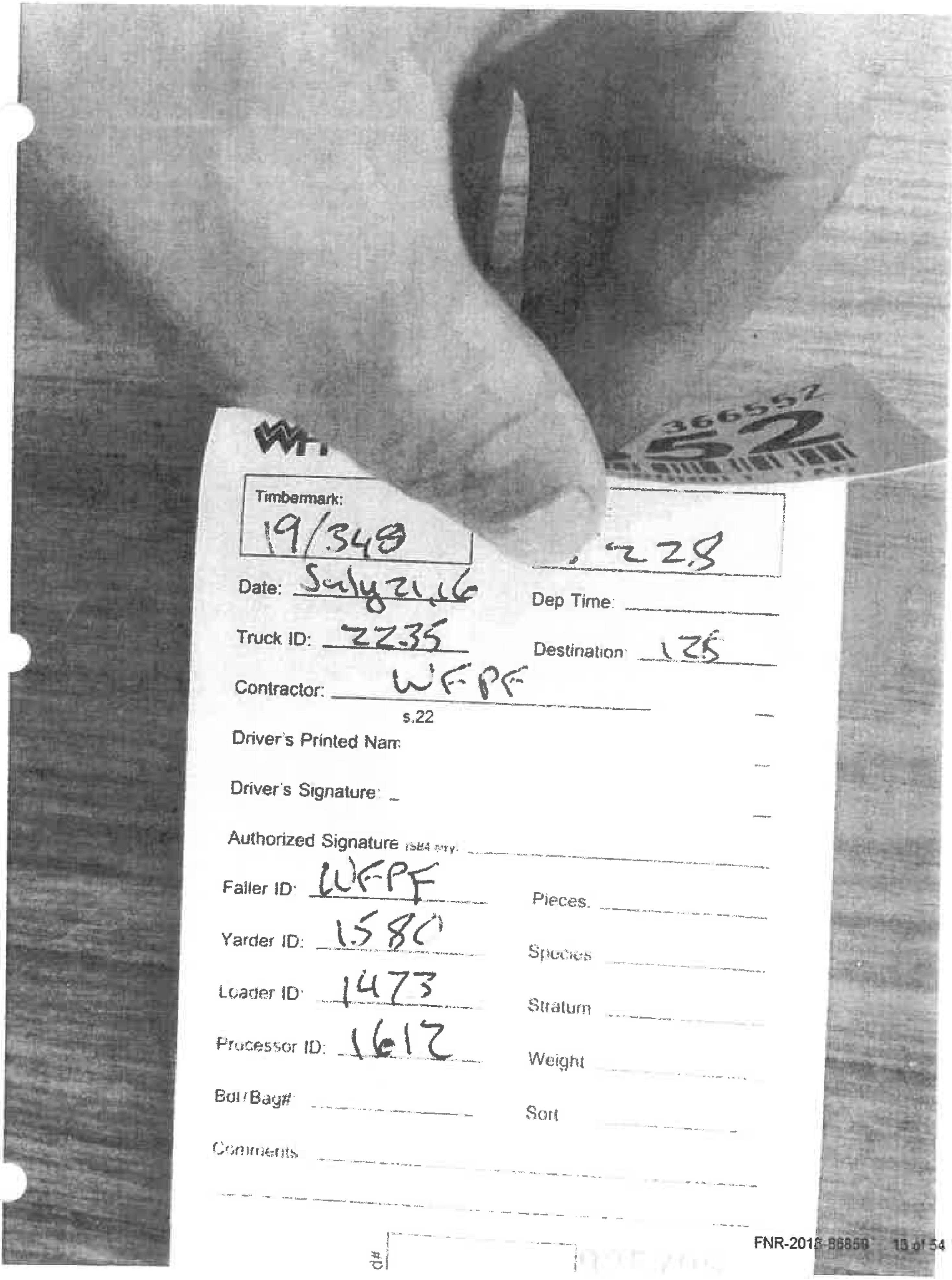
A site visit was conducted at the Western Forest Products sort at Nesook Bay to determine how timber was being marked.
Woods foreman was not on site. An employee responsible for bundling timber provided the foreman's contact information.
The employee stated that all timber coming from the harvest site was hammer marked by the driver at the site prior to departing, the timber remained on the log hauler while being bundled at the sort, a bundle tag was then attached, and finally the bundled timber on the log hauler would be dumped into the water to be boomed for

transportation.

Load slips were inspected for compliance with the Timber Marking and Transportation Regulation, Documentation Requirements, Section 10.
Non-Compliance of section 10 (2)(c) - the date on and time at which the transport of the timber begins were found on load slip(s):
925794, 925793, 864737, 925725, 923153, 864736, 864735, 923087, 923088, 925796

Western Forest Products Woods Foreman will be contacted on the inspection findings.

Natural Resource Officer: [Adam Vojnic] Signature: X I certify that this inspection conforms to Ministry compliance procedures.	**Sent to:** 300 Western Dr Gold River, BC V0P 1G0
Attachments and Comments: 1) Western Forest Products - Nesook Bay, Load Slips.pdf Load Slips Non-Compliance of section 10 (2)(c) - the date on and time at which the transport of the timber begins	**Delivered via:** Email: ☐ Fax: ☐ Mail: ☐ Hand Delivery: ☒



Timbermark: 19/348

228

Date: July 21, 16

Dep Time:

Truck ID: 2235

Destination: 125

Contractor: WFPF

s.22

Driver's Printed Nam

Driver's Signature:

Authorized Signature (SB4 only)

Faller ID: WFPF

Pieces:

Yarder ID: 1580

Species:

Loader ID: 1473

Stratum:

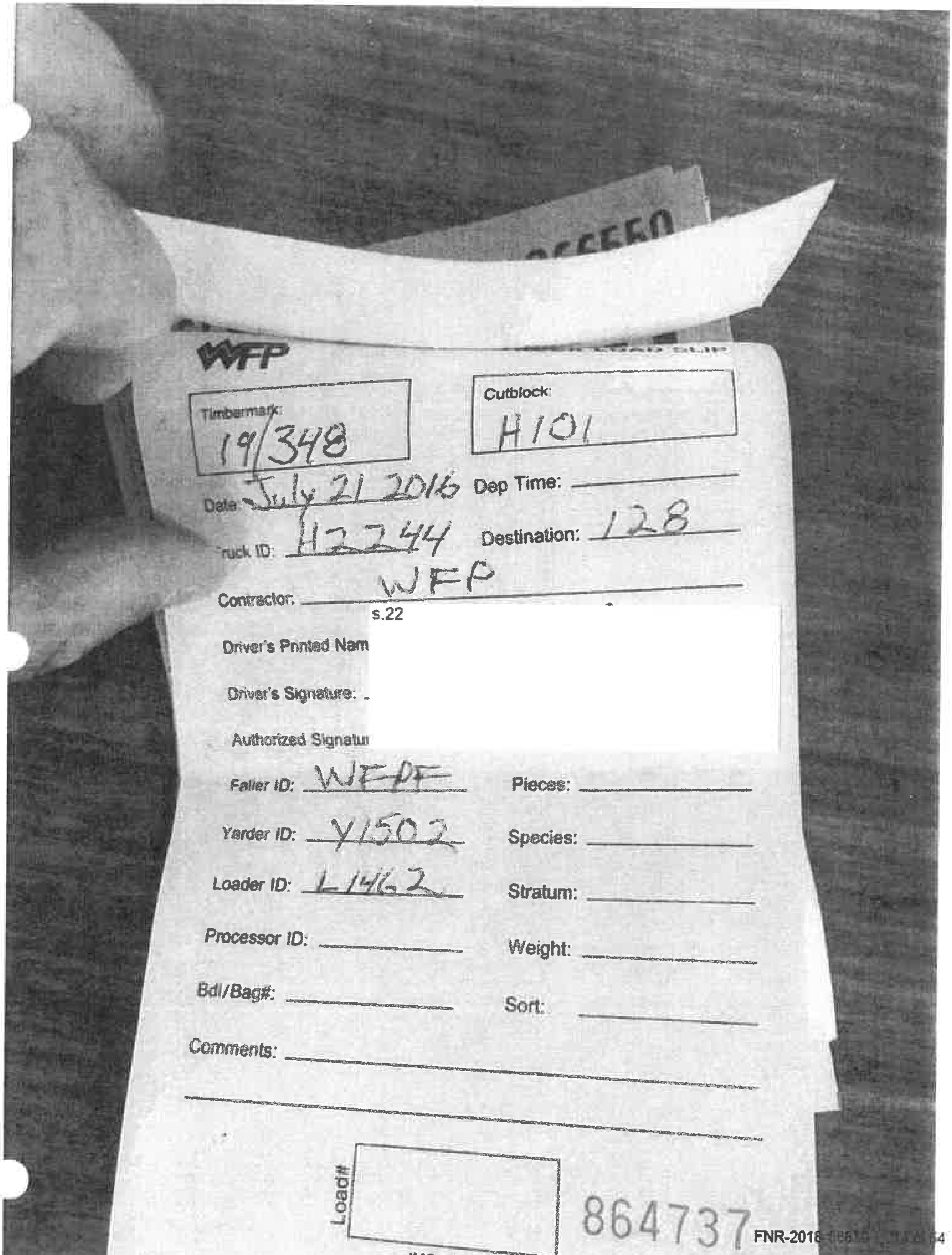
Processor ID: 1612

Weight:

Bol/Bag#:

Sort:

Comments:


WFP

Timbermark: 19/348

Cutblock: H101

Date: July 21 2016 Dep Time: ___

Truck ID: H2244 Destination: 128

Contractor: WFP

s.22 [redacted]

Driver's Printed Nam [redacted]

Driver's Signature: [redacted]

Authorized Signatu [redacted]

Faller ID: WFPF Pieces: ___

Yarder ID: Y1502 Species: ___

Loader ID: L1462 Stratum: ___

Processor ID: ___ Weight: ___

Bdl/Bag#: ___ Sort: ___

Comments: ___

Load#

864737

(MOF Comp...

FNR-2018-

WFP

Timbermark: 19/355

Cutblock: Q232

Date: 7/21/16

Dep Time: ______

Truck ID: 2245

Destination: 128

Contractor: WFP

s.22

Driver's Printed Na[redacted]

Driver's Signature: [redacted]

Authorized Signature (SB4 only): ______

Faller ID: WFP·F

Pieces: ______

Yarder ID: Y 1600

Species: C.R.

Loader ID: L 1410

Stratum: ______

Processor ID: ______

Weight: ______

Bdl/Bag#: ______

Sort: ______

Comments: ______

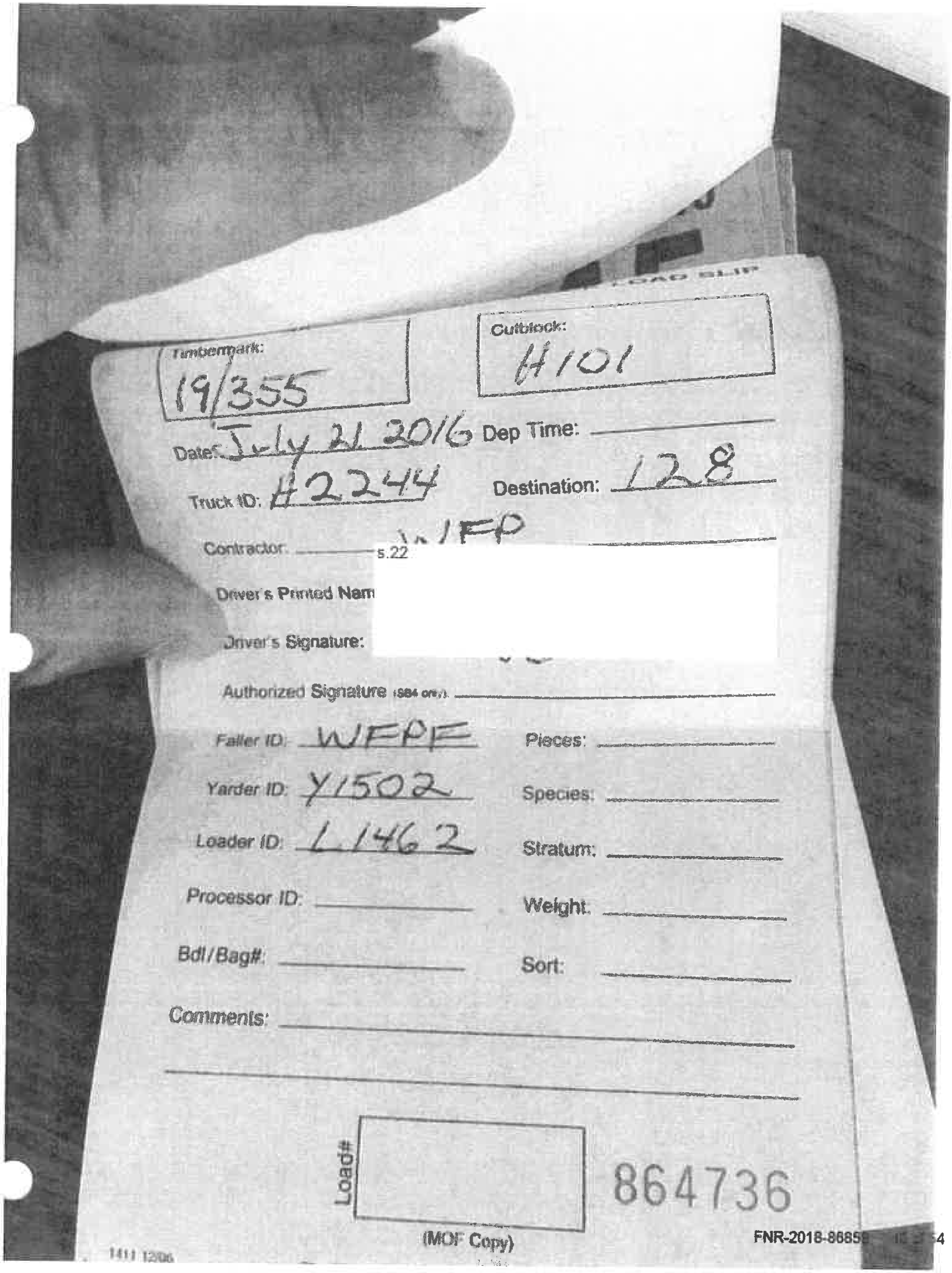
Load#

923088

1511 12/06

(MOF Copy)

FNR-2018-86859



LOAD SLIP

Timbermark: 19/355

Cutblock: H101

Date: July 21 2016 Dep Time:

Truck ID: #2244 Destination: 128

Contractor: WFP

s.22

[redacted]

Driver's Printed Nam[redacted]

Driver's Signature: [redacted]

Authorized Signature (SB4 only):

Faller ID: WFPF Pieces:

Yarder ID: Y1502 Species:

Loader ID: L1462 Stratum:

Processor ID: Weight:

Bdl/Bag#: Sort:

Comments:

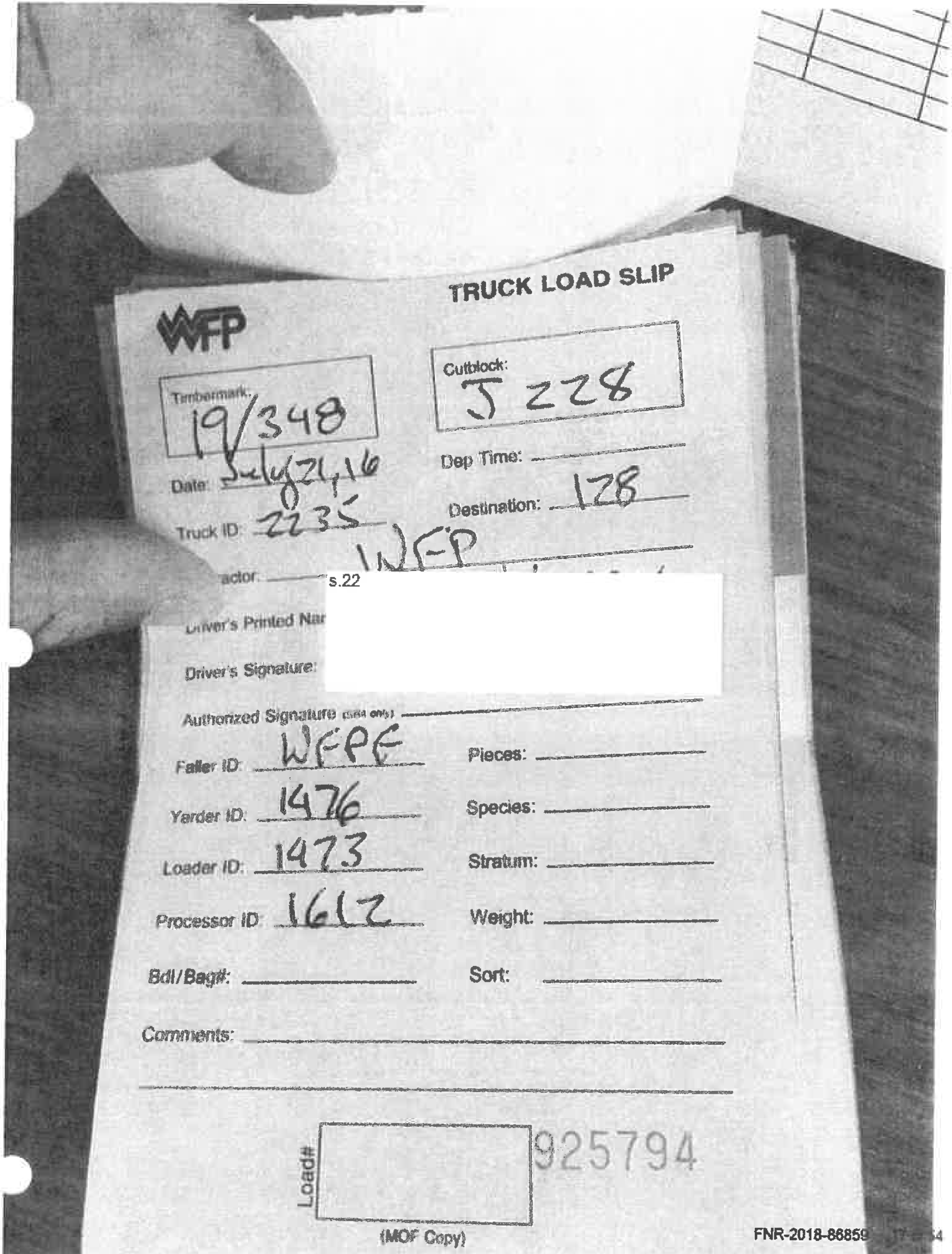
Load#

864736

(MOF Copy)

1411 12/06

FNR-2018-8885



TRUCK LOAD SLIP

WFP

Timbermark: 19/348

Cutblock: J 228

Date: July 21, 16

Dep Time:

Truck ID: 2235

Destination: 128

...actor: WFP

s.22

Driver's Printed Na...

Driver's Signature:

Authorized Signature (SBM only)

Faller ID: WFPF

Pieces:

Yarder ID: 1476

Species:

Loader ID: 1473

Stratum:

Processor ID: 1612

Weight:

Bdl/Bag#:

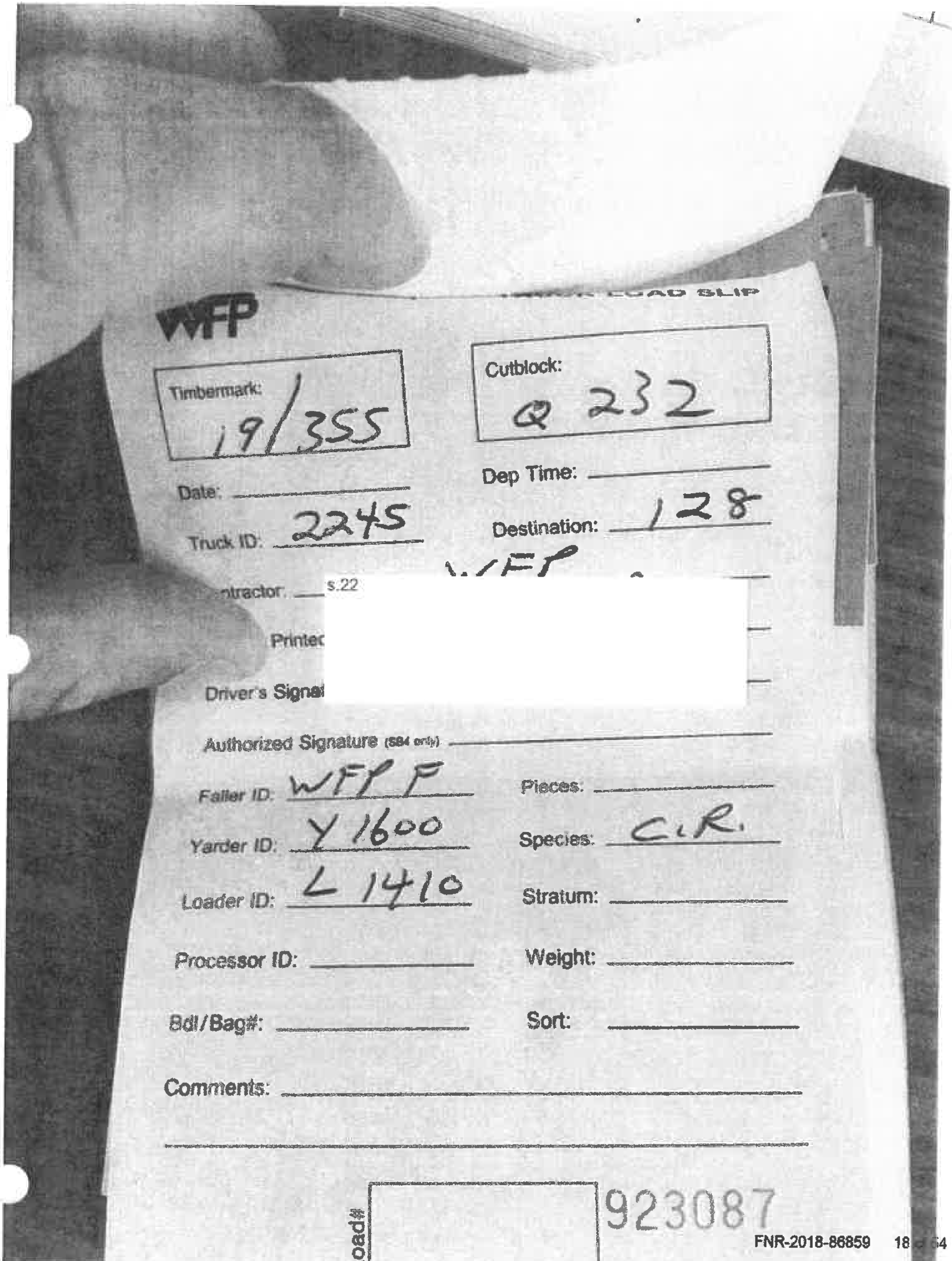
Sort:

Comments:

Load# 925794

(MOF Copy)

FNR-2018-86859


WFP ... LOAD SLIP

Timbermark: 19/355

Cutblock: Q 232

Date: ______

Dep Time: ______

Truck ID: 2245

Destination: 128

...ntractor: s.22 [redacted]

Printed [redacted]

Driver's Signa[redacted]

Authorized Signature (SB4 only) ______

Faller ID: WFP F

Pieces: ______

Yarder ID: Y 1600

Species: C.R.

Loader ID: L 1410

Stratum: ______

Processor ID: ______

Weight: ______

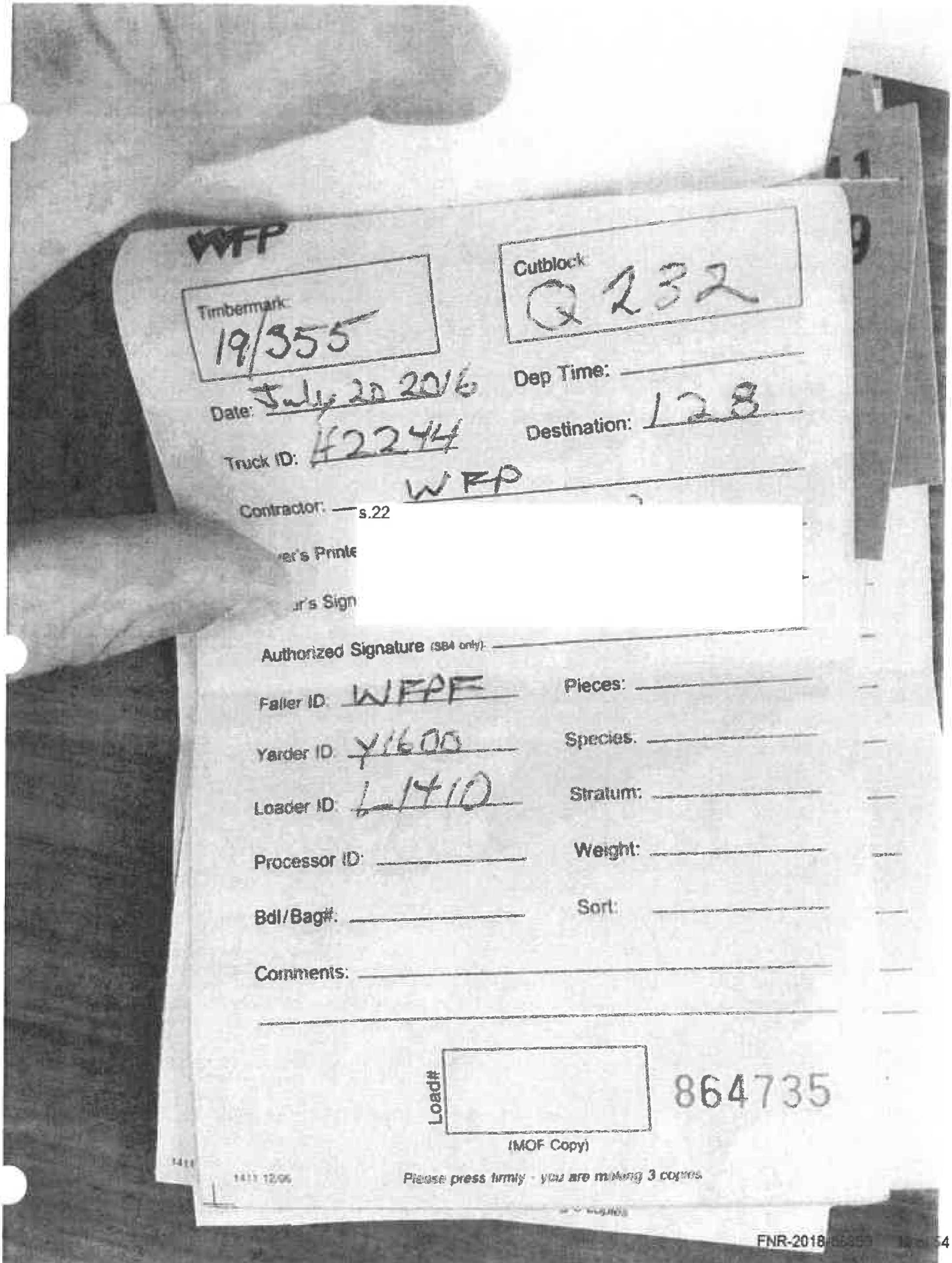
Bdl/Bag#: ______

Sort: ______

Comments: ______

Load#

923087



WFP

Timbermark: 19/355

Cutblock: Q232

Date: July 20 2016

Dep Time:

Truck ID: F2244

Destination: 128

Contractor: WFP

s.22

...er's Printe...

...r's Sign...

Authorized Signature (SB4 only):

Faller ID: WFPF

Pieces:

Yarder ID: Y1600

Species:

Loader ID: L1410

Stratum:

Processor ID:

Weight:

Bdl/Bag#:

Sort:

Comments:

Load#

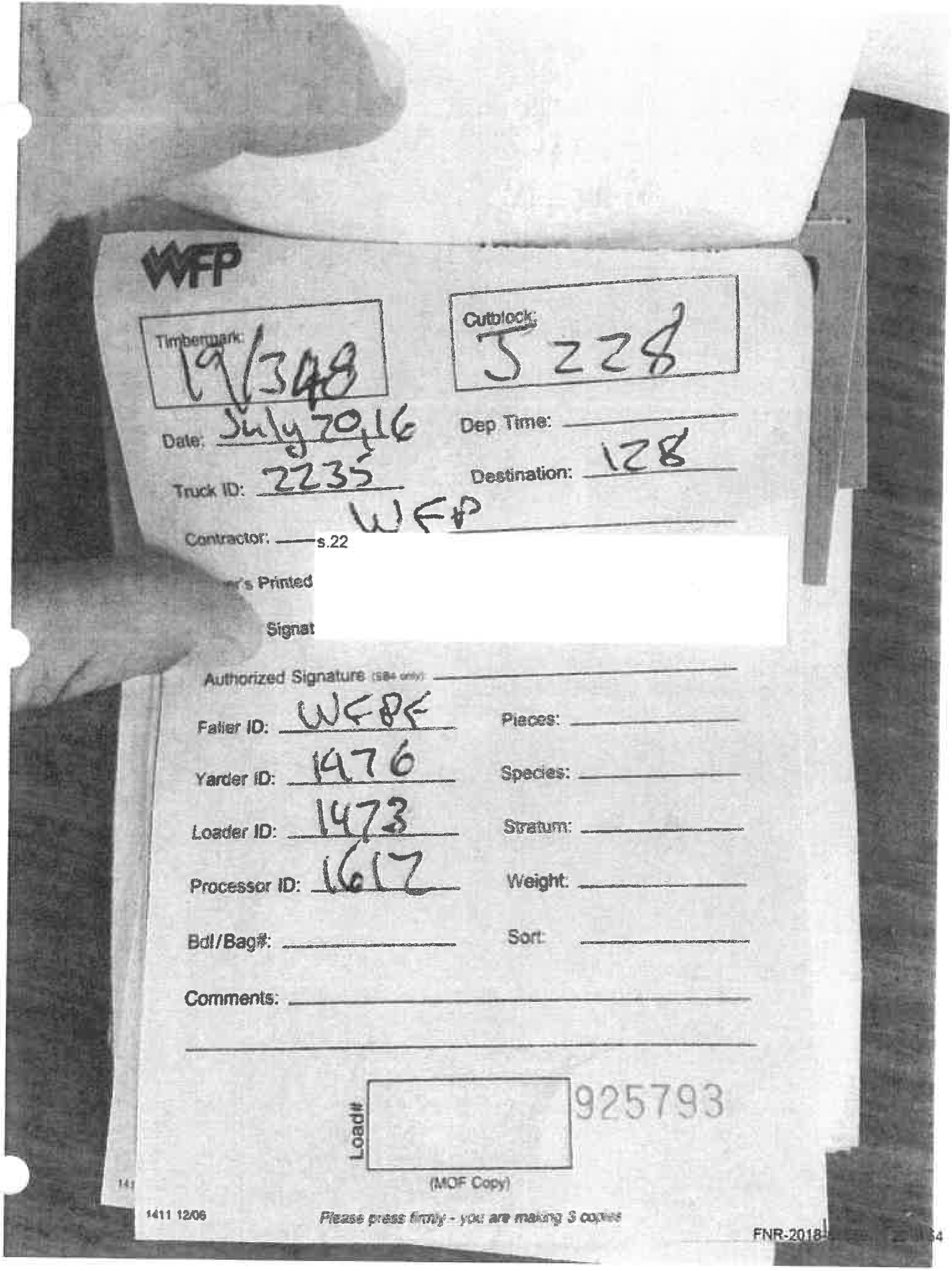
864735

(MOF Copy)

1411 12/06

Please press firmly - you are making 3 copies

FNR-2018-[illegible] Page 54



WFP

Timbermark: 19/348

Cutblock: J 228

Date: July 20, 16

Dep Time:

Truck ID: 2235

Destination: 128

WFP

Contractor: s.22 [redacted]

...er's Printed

Signat

Authorized Signature (SB4 only)

Faller ID: WFBF

Pieces:

Yarder ID: 1476

Species:

Loader ID: 1473

Stratum:

Processor ID: 1617

Weight:

Bdl/Bag#:

Sort:

Comments:

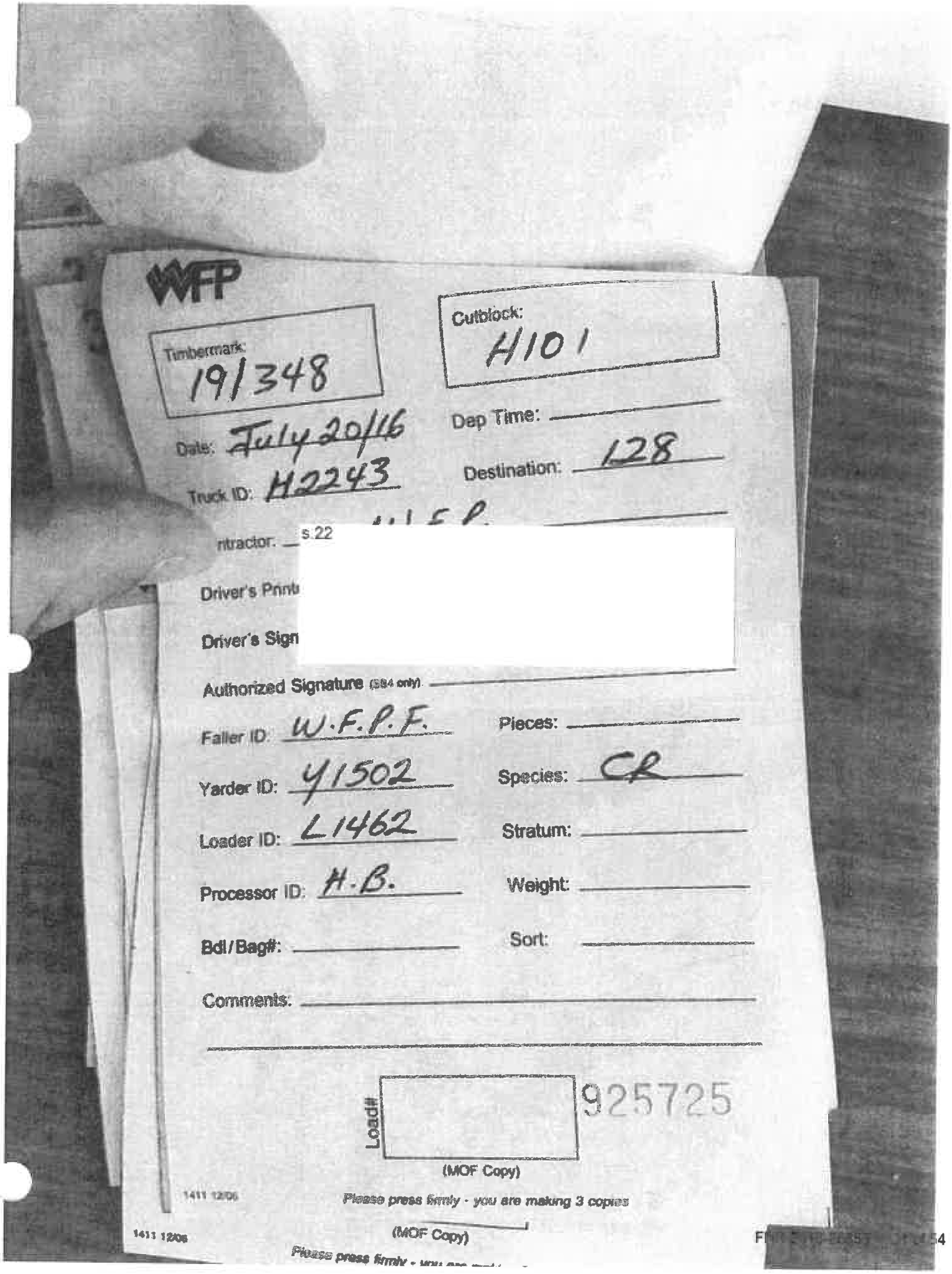
Load#

925793

(MOF Copy)

1411 12/06

Please press firmly - you are making 3 copies



WFP

Timbermark: 19/348

Cutblock: H101

Date: July 20/16

Dep Time:

Truck ID: H2243

Destination: 128

...ntractor: s.22 [redacted]

Driver's Print [redacted]

Driver's Sign [redacted]

Authorized Signature (384 only)

Faller ID: W.F.P.F.

Pieces:

Yarder ID: Y1502

Species: CR

Loader ID: L1462

Stratum:

Processor ID: H.B.

Weight:

Bdl/Bag#:

Sort:

Comments:

Load# 925725

(MOF Copy)

1411 12/06

Please press firmly - you are making 3 copies

1411 12/06

(MOF Copy)

WFP

TRUCK LOAD SL

Timbermark: 19/348	Cutblock: H101

Date: July 21/16 Dep Time: ______

Truck ID: H2243 Destination: 128

Contractor: — s.22 W.F.P.

Driver's Print

Driver's Sign

Signature (SB4 only): ______

.F.P.F. Pieces: ______

/1502 Species: CR

D: L1462 Stratum: ______

essor ID: H.B. Weight: ______

dl/Bag#: ______ Sort: ______

Comments: ______

IP #

54

Case Summary

Case ID:	DCR-34723	**Type:**	Incident	**Status:**	Closed
Opened Date:	2016-08-04	**Admin Org Unit:**	Campbell River Natural Resource District	**Geo Org Unit:**	Campbell River Natural Resource District

Details

Case ID:	DCR-34723	**Opened Date:**	2016-08-04
Type:	Incident	**Discovery Date:**	2016-07-21
Status:	Closed	**Admin Org Unit:**	Campbell River Natural Resource District
Opened By:	Adam Vojnic	**Geo Org Unit:**	Campbell River Natural Resource District
Lead Investigator:	Adam Vojnic	**Source:**	BC Forest Service
FPB File #:		**Source Ref #:**	
Inspection ID:		**Other Source Agency:**	
Regional Review of Prosecution Test?:	No	**Date of Prosecution Test Review:**	

Case Description: July.21, 2016 - Nesook Bay, Western Forest Products TFL19 Boom Inspection

An inspection was conducted on boom NK0NS16-00-21 by the C&E Branch, Ministry of Forest, Lands and Natural Resource Operations at Nesook Bay.

The inspection revealed Bundle Tag# 366450 contained timber which was hammer marked with both Timber Mark: 19/355 & 19/348.
Bundle Tag # 366450 did have all bundle cable intact and no loose timber was observed.

A site visit was conducted at the Western Forest Products sort at Nesook Bay to determine how timber was being marked.
Woods foreman was not on site. An employee responsible for bundling timber provided the foreman's contact information.
The employee stated that all timber coming from the harvest site was hammer marked by the driver at the site prior to departing, the timber remained on the log hauler while being bundled at the sort, a bundle tag was then attached, and finally the bundled timber on the log hauler would be dumped into the water to be boomed for transportation.

Load slips were inspected for compliance with the Timber Marking and Transportation Regulation, Documentation Requirements, Section 10.
Non-Compliance of section 10 (2)(c) - the date on and time at which the transport of the timber begins were found on load slip(s):
925794, 925793, 864737, 925725, 923153, 864736, 864735, 923087, 923088, 925796

Western Forest Products Woods Foreman Doug Thompson was contacted on the inspection findings.

Sept.27, 2016
NRO Vojnic issued Violation ticket to Western Forest Products Inc for TMTR Sec 10(2)(e)
NRO Vojnic issued Warning ticket to Western Forest Product Inc for FOA Sec 84(3)

Contraventions :

Case ID:	DCR-34723	**Type:**	Incident	**Status:**	Closed
Opened Date:	2016-08-04	**Admin Org Unit:**	Campbell River Natural Resource District	**Geo Org Unit:**	Campbell River Natural Resource District

Contravention 2. Timber Marking & Transportation Regulation (FA) 10 (2)

Contravention Status:	Deferred	**Determination Numbers:**	
Est. Incident Date:	2016-07-21	**Appeal Numbers:**	
Site:	TFL19 348/J228	**CIMS Inspection ID:**	
Client:	WESTERN FOREST PRODUCTS INC.; 00149081; 18	**Client Address:**	NOOTKA FOREST OPERATION, 300 WESTERN DRIVE, GOLD RIVER, BC, V0P1G0
Joint Clients:			
Investigation Cost:	$ 0.00	**Date Sent for OTBH:**	
Search Warrent	No	**SDM:**	
Date Transferred:		**Prosecution Agency:**	
Transferred To:		**Prosecution Contact:**	
Transfer Office		**Prosecution Phone:**	
Transfer Contact:		**Date Sent to Prosecution:**	
Transfer Phone:		**Prosecution Date:**	
		Prosecution Successful?:	

Enforcement Actions:

Enforcement Action 1.

Type:	Violation Ticket	**EA Status:**	Invalid
Latest Decision:		**Outstanding Decision:**	
Outcome Status:		**Comments:**	
Can Be Processed?:	Yes	**Activity Complete:**	Yes
Ticket #:	AH90483290	**Vehicle Plate #:**	
Driver's License:		**Vehicle Prov/State:**	
Other ID:		**Registered Owner:**	
Birthdate:		**Young Offender?:**	
Issued By:	Adam Vojnic	**Service Date:**	2016-09-27
Served By:	Adam Vojnic	**Appeal Period:**	30 days

	Status	Fine Amount	Count Amount
2. Timber Marking & Transportation Regulation (FA) 10 (2)	In Progress	$ 150.00	$ 173.00

Compliance Actions:

Clients:

Name	Address	Client Number	Location Code	Joint Clients
WESTERN FOREST PRODUCTS INC.	NOOTKA FOREST OPERATION, 300 WESTERN DRIVE, GOLD RIVER, BC, V0P1G0	00149081	18	

Sites:

Bus Area	Site	Latitude	Longitude	Description
Harvest	TFL19 348/J228	0/ 00/ 50	0/ 00/###	Western Forest Products TFL 19 Nesook Bay Sort

Notes:

Date	Name	Comment
2017-03-28	Adam Vojnic	AH90483290 glty by exp Oct 28 2016 $173 o/s

INSPECTION REPORT

[redacted] **RECORD ID:** 046270
IDIR\ s.15
02:15 Mar 19, 2019

Natural Resource Officer:
Levi Bauder

Region: West Coast
Field Unit: Campbell River

Date of Inspection:
December 15, 2016

Client:
WESTERN FOREST PRODUCTS INC., WEST ISLAND TIMBERLANDS

In Attendance:
Adam Vojnic, C&E

Compliance Status:
Compliant

Client Contact Information:
WEST ISLAND REGION,_118 - 1334 ISLAND HIGHWAY,

CAMPBELL RIVER,BC,CANADA
V9W8C9

Latitude:
49.9579

Longitude:
-126.861061

Location Description:
30 km Mark on Fair Harbour Main

Primary Tenure/Authorization:
19/446/NRIS

Secondary Tenure/Authorization:

Alleged Non-Compliance Summary:

aNC#	Estimated Incident Date	Parent Act	Act/Regulation	Section	Description	Action Taken

Warning Ticket #:

ERA Case #:

Description and Comments:

NRO's conducted a TMTR inspection on two loaded logging trucks at the 30Km mark on Fair Harbour Main. Bauder inspected a Lemare Lake off highway logging truck fully loaded with Cedar and Fir. The truck was well marked with the TM hammered on almost every log front and back as well as side marking. The load slip was filled out correctly with the legislated sections. The truck is hauling for Western Forest Products TFL 19/446 out of cutblock Z11

Natural Resource Officer: [Levi Bauder]

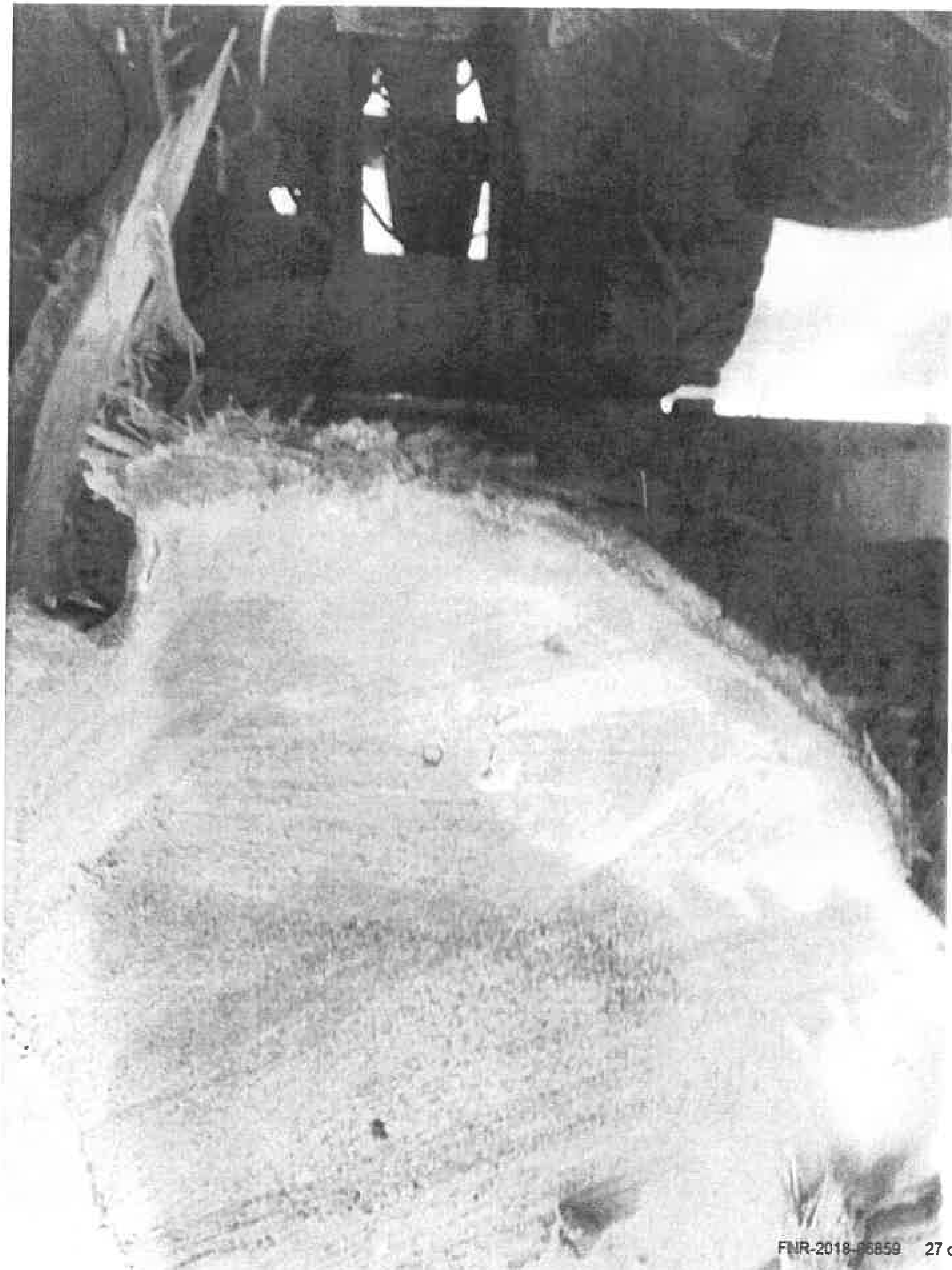
Signature: X

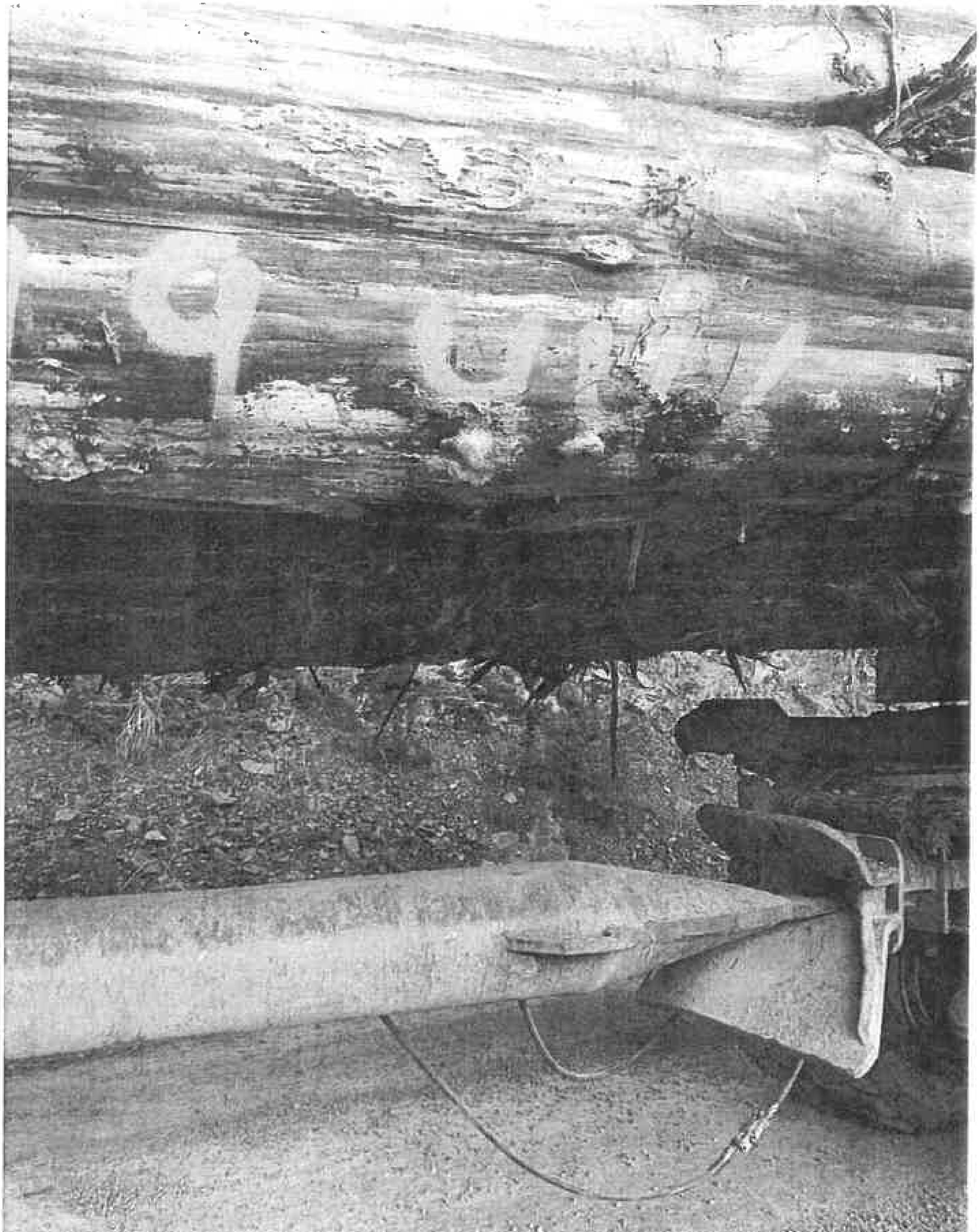
I certify that this inspection conforms to Ministry compliance

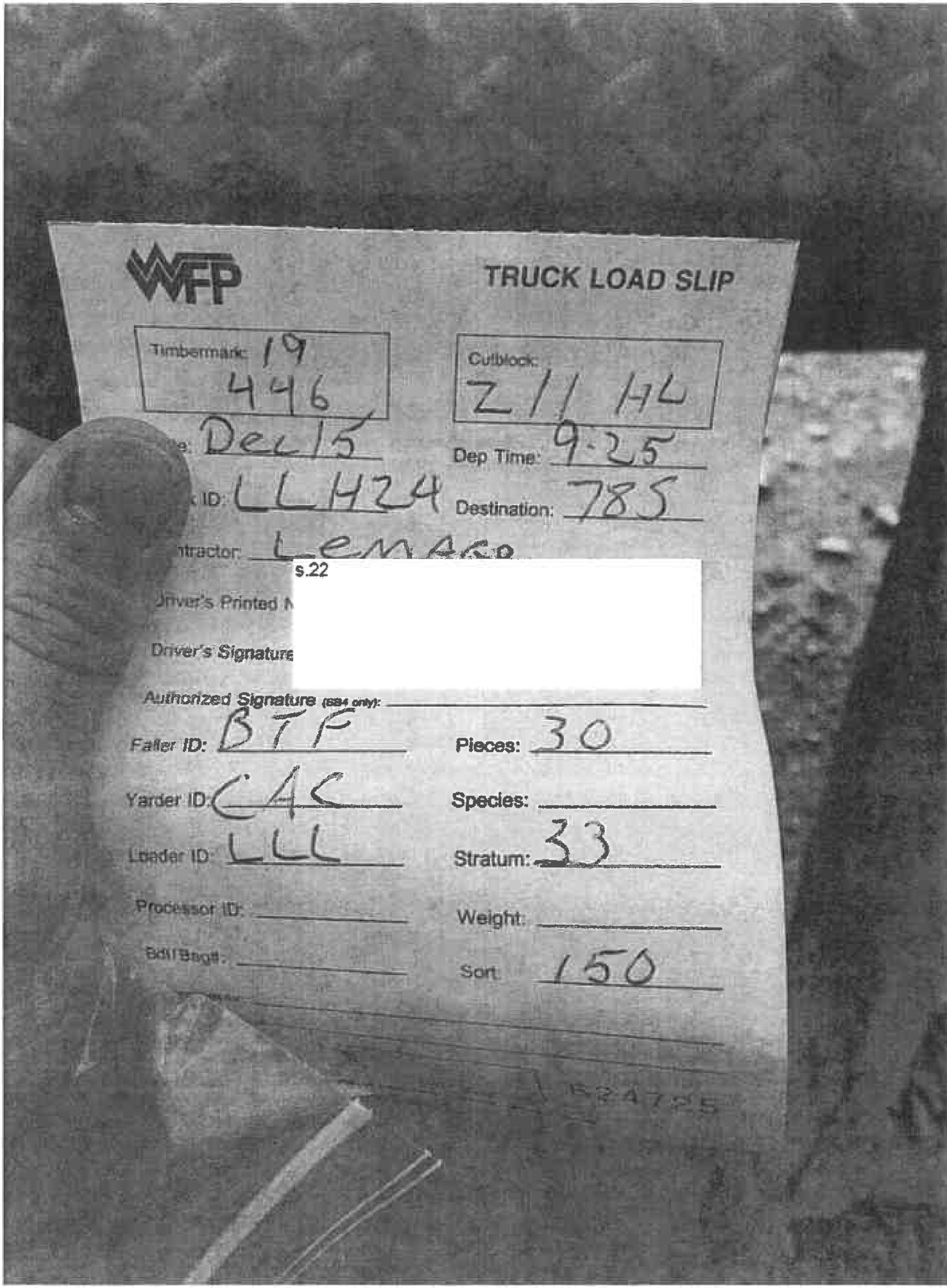
Sent to:
WEST ISLAND REGION,_118 - 1334 ISLAND HIGHWAY,

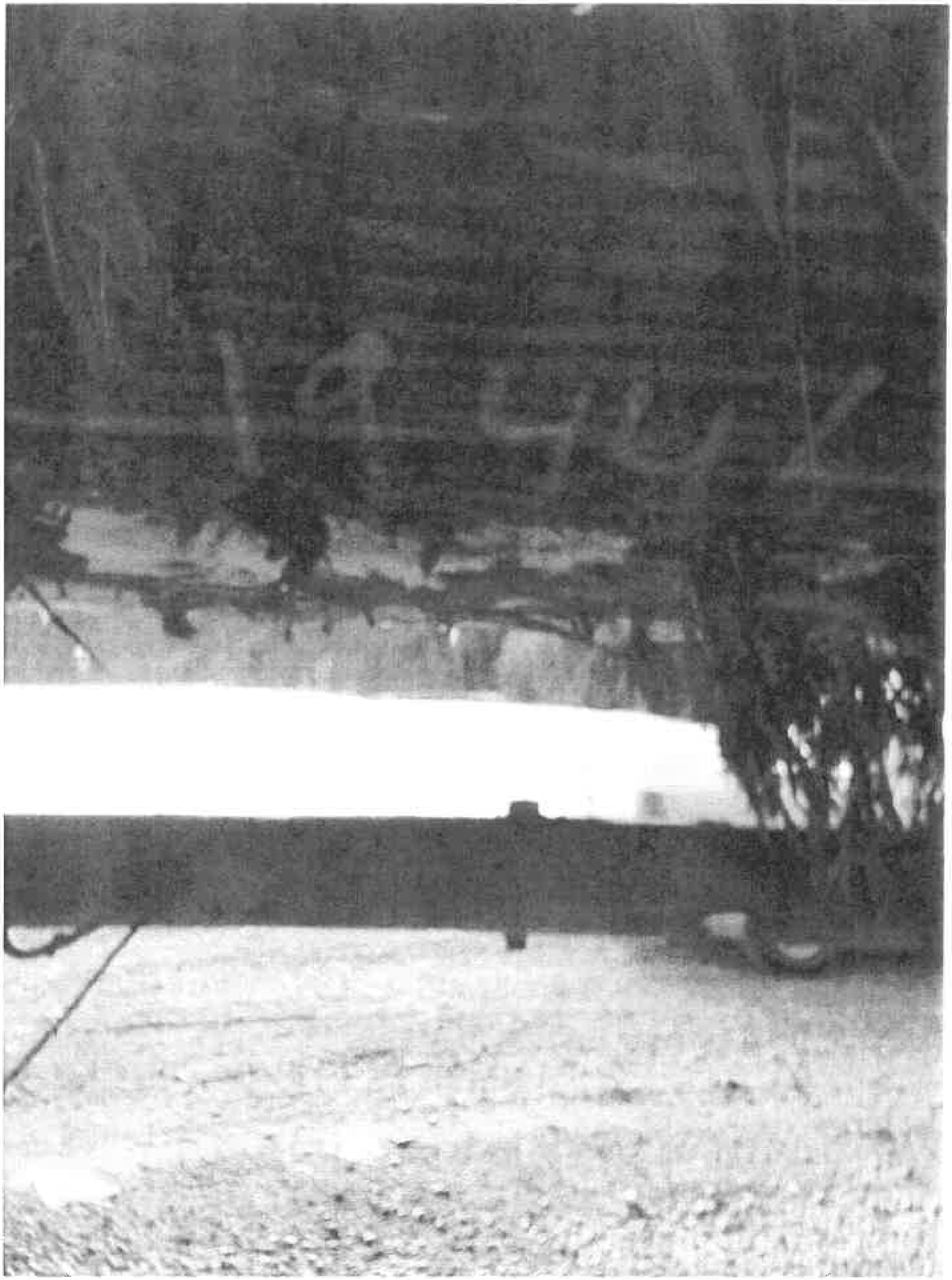
CAMPBELL RIVER,BC,CANADA
V9W8C9

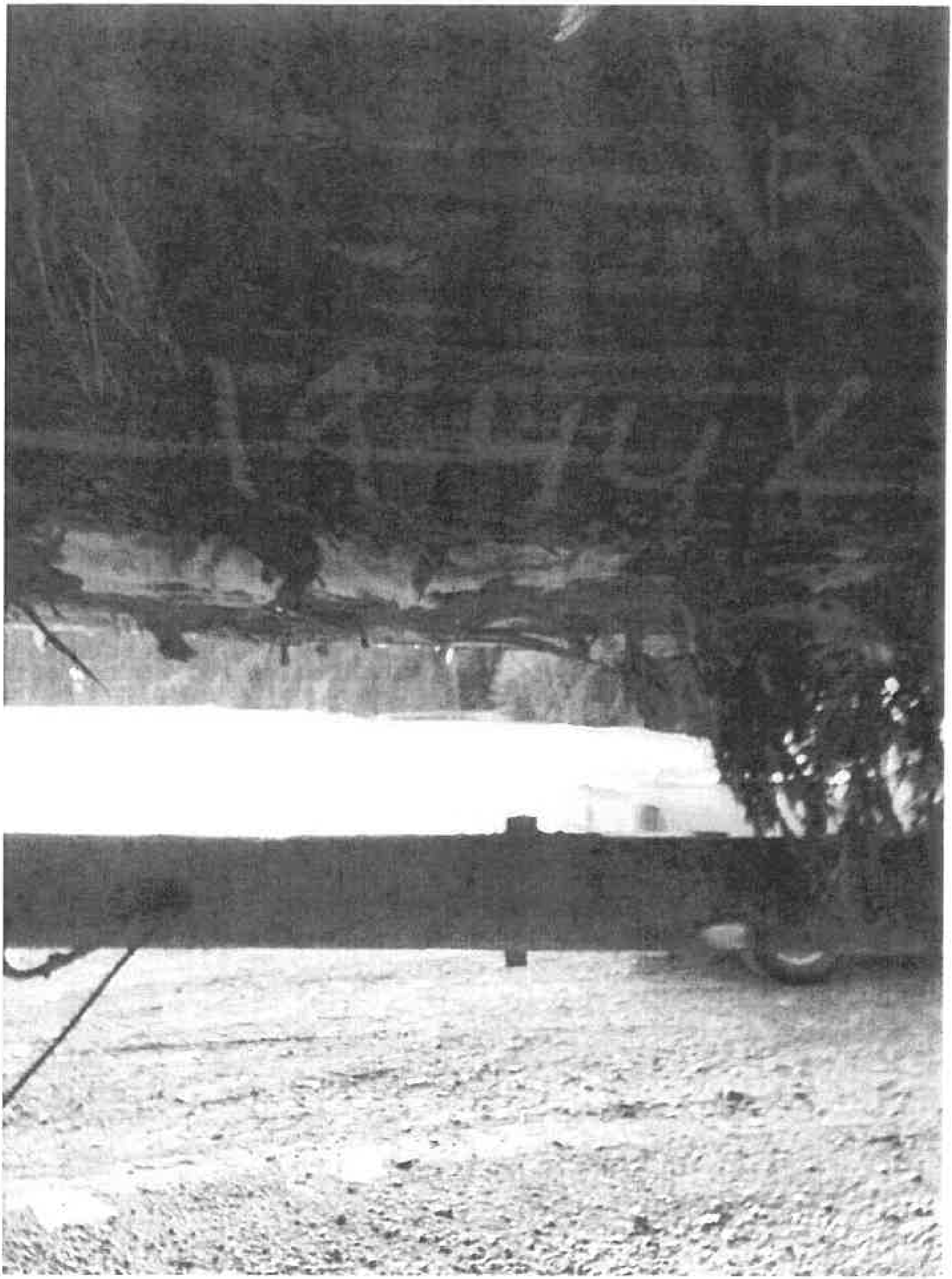
Attachments and Comments:	**Delivered via:**
1) Lamare TMTR.pdf Lemare Lake TMTR Pics	Email: ☐ Fax: ☐ Mail: ☐ Registered Mail: ☐ Hand Delivery: ☒



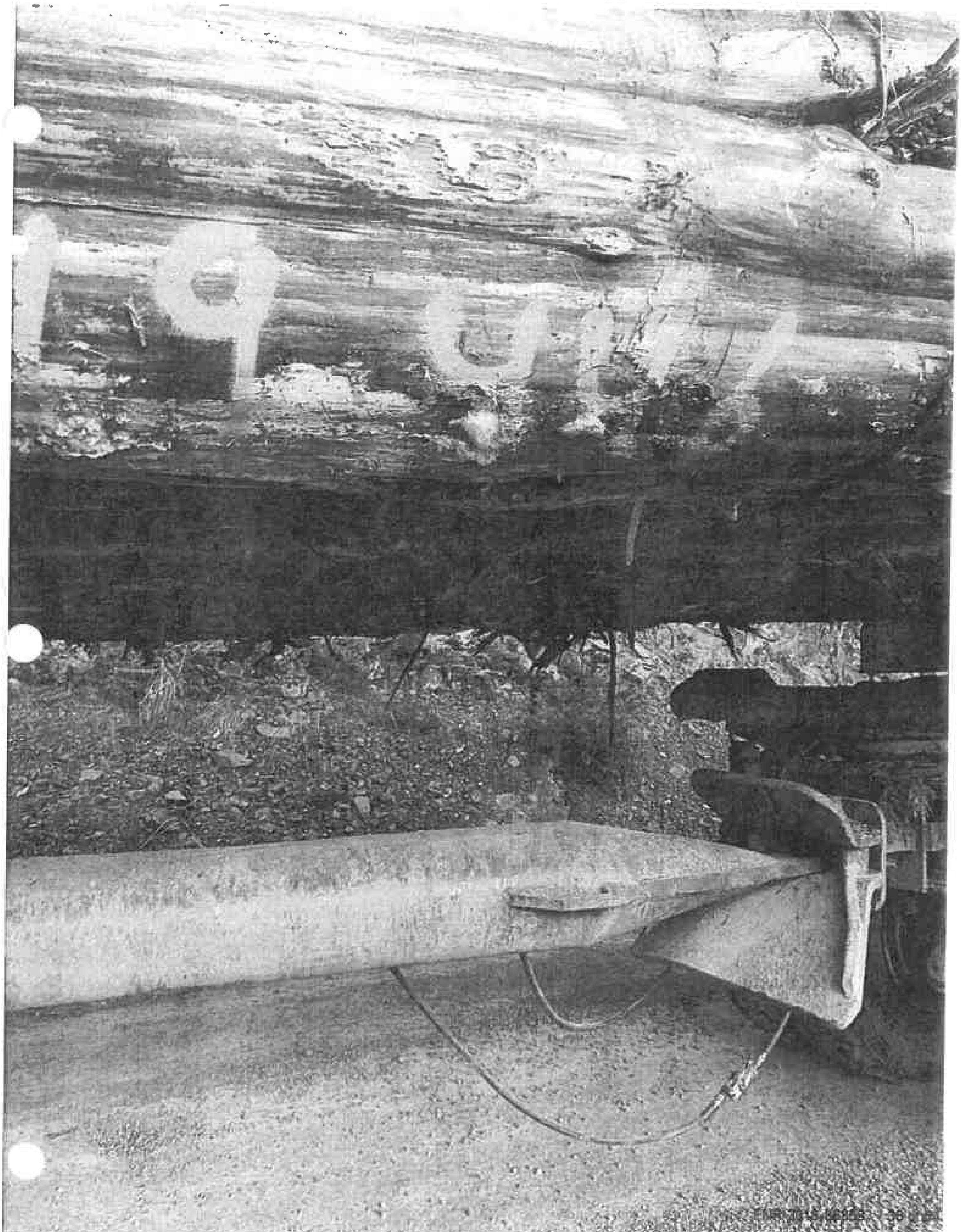


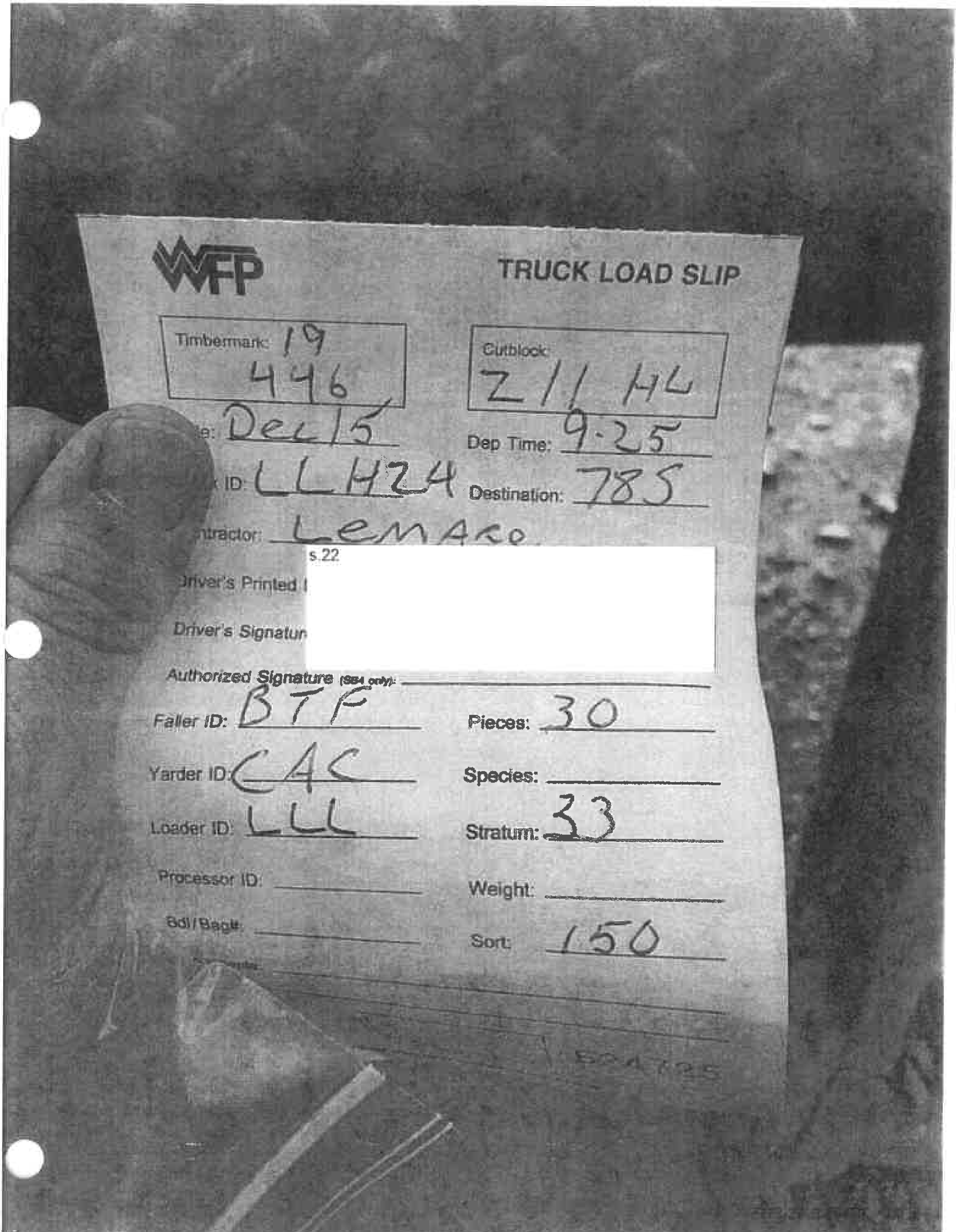

WFP
TRUCK LOAD SLIP
Timbermark: 19 446
Cutblock: Z11 HL
Dec 15
Dep Time: 9:25
LLH24
Destination: 785
s.22
Driver's Signature
Authorized Signature (SB4 only):
Faller ID: BTF
Pieces: 30
Yarder ID: CAC
Species:
Loader ID: LLL
Stratum: 33
Processor ID:
Weight:
Sort: 150






19
44




WFP

TRUCK LOAD SLIP

Timbermark: 19 446

Cutblock: Z11 HL

e: Dec 15

Dep Time: 9·25

ID: LLH24

Destination: 785

ntractor: LeMAco

s.22 [redacted]

Driver's Printed

Driver's Signatur

Authorized Signature (SB4 only):

Faller ID: BTF

Pieces: 30

Yarder ID: CAC

Species:

Loader ID: LLL

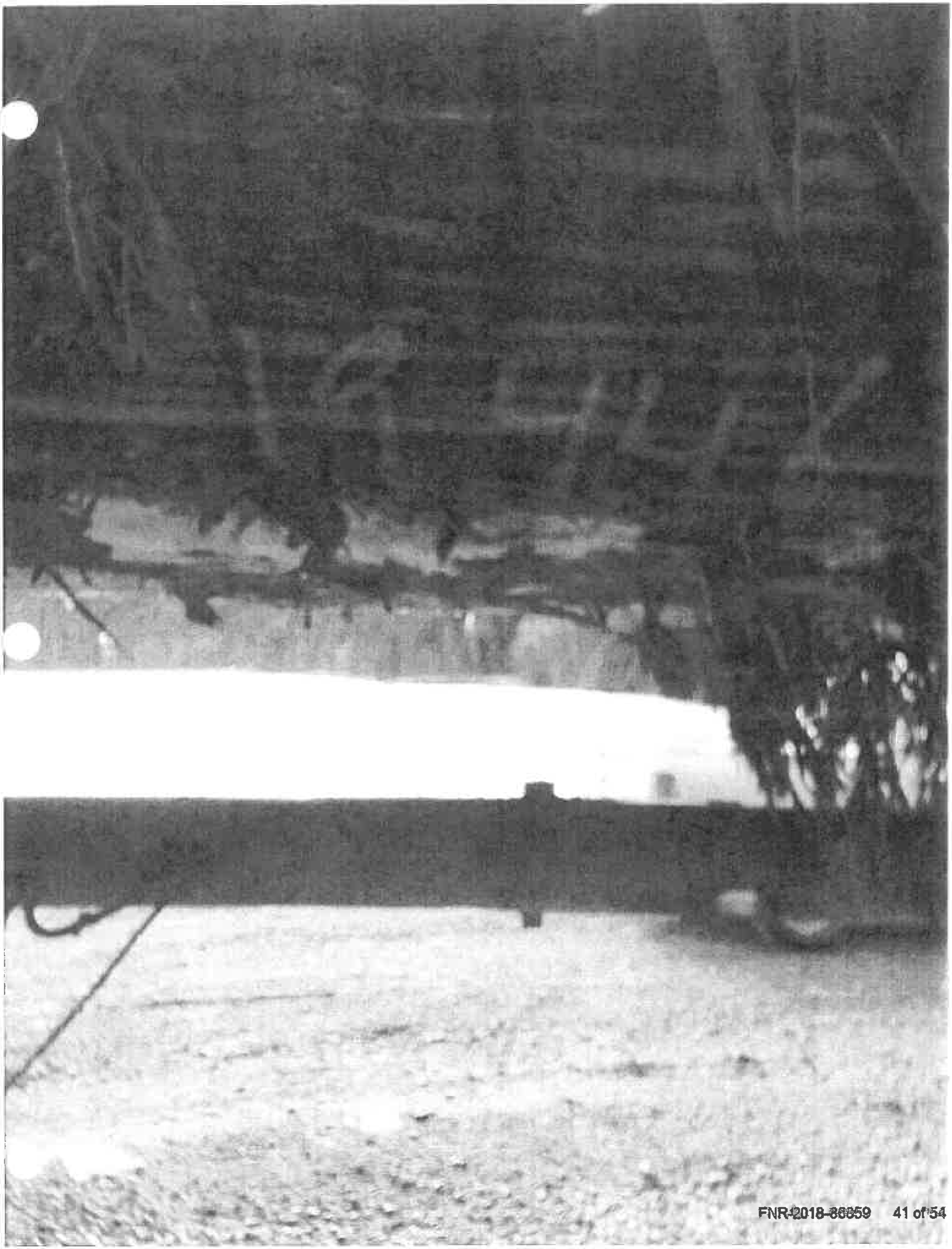
Stratum: 33

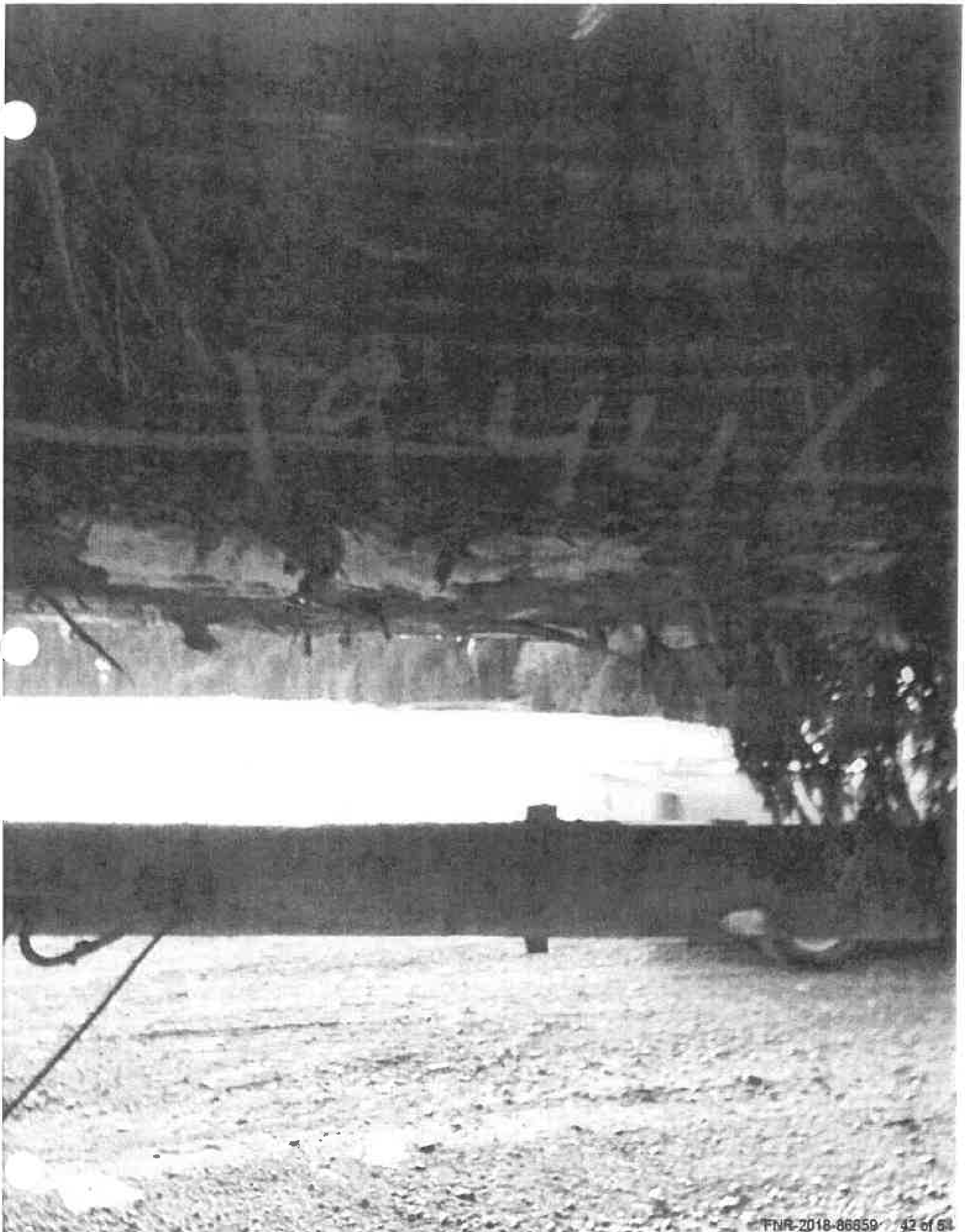
Processor ID:

Weight:

Bdl/Bag#:

Sort: 150


FNR-2018-86859 41 of 54


FNR-2018-06859 42 of 54


19
44

INSPECTION REPORT

RECORD ID: 060146
IDIR s.15
02:49 Mar 19, 2019

Natural Resource Officer:	Region: West Coast	Date of Inspection:
Adam Vojnic	Field Unit: Campbell River	July 11, 2017

Client:	In Attendance:	Compliance Status:
Western Forest Products Inc. Gold River	Paul SACKNEY, C&E	Compliant

Client Contact Information:
300 Western Dr
Gold River, BC
V0P 1G0

Latitude:
49.878889

Longitude:
-126.105

Location Description:
WFP TFL 19/359

Primary Tenure/Authorization:
TFL19/FTA

Secondary Tenure/Authorization:

Alleged Non-Compliance Summary:

aNC#	Estimated Incident Date	Parent Act	Act/Regulation	Section	Description	Action Taken

Warning Ticket #:

ERA Case #:

Description and Comments:

NROs with the C&E Branch conducted a Wildfire Preparedness Inspection on WFP TFL 19/357 Block N100.

Fire watchers were present when Officers attended the site of Industrial Activity. 1 mechanic left onsite after 1400hrs. 5machines onsite which included yarders, processors and a cable yarder.

Officers spoke with the mechanic onsite which stated that the crew was on early shutdown, stated that the danger class was 4 and brought the NROs to the water deliver system.

Water Delivery System included a Wajax Mark III pump in a creek within Block N100. Placed next to the pump are 6 unopened boxes of 100ft hose + 1, 100ft hose laid out next to the Wajax that was not connected. NRO Sackney determined range using range finder = 280m to the site of the high risk industrial activity.

Officers headed to WFP Gold River office and met with WFP Supervisor Jeff Payne to speak about the inadequate Fire Suppression system onsite at Block N100. Mr. Payne states that there is a Water Truck at Block N155, 15min away, we also have heli-logging on the other side of the hill next to Block N100 which has a bucket attachment. NRO Sackney requested representative weather data for Block N100 and Mr. Payne will provide next working day.

Natural Resource Officer: [Adam Vojnic] Signature: X I certify that this inspection conforms to Ministry compliance	**Sent to:** 300 Western Dr Gold River, BC V0P 1G0
Attachments and Comments: 1) 028.JPG Unopened Fire Hose 2) 026.JPG Water Delivery System 3) 027.JPG Cable Yarder Site 4) inspectionReport60146.pdf INSPECTION Report	**Delivered via:** Email: ☐ Fax: ☐ Mail: ☐ Registered Mail: ☐ Hand Delivery: ☐

RECORD ID: 060146
IDIR s.15
02:49 Mar 19, 2019

INSPECTION REPORT

Natural Resource Officer: Adam Vojnic	**Region:** West Coast **Field Unit:** Campbell River	**Date of Inspection:** July 11, 2017
Client: Western Forest Products Inc. Gold River	**In Attendance:** Paul SACKNEY, C&E	**Compliance Status:** Compliant

Client Contact Information:
300 Western Dr
Gold River, BC
V0P 1G0

Latitude: 49.878889

Longitude: -126.105

Location Description:
WFP TFL 19/359

Primary Tenure/Authorization:
TFL19/FTA

Secondary Tenure/Authorization:

Alleged Non-Compliance Summary:

aNC#	Estimated Incident Date	Parent Act	Act/Regulation	Section	Description	Action Taken

Warning Ticket #:

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Img : 028.JPG

Img : 026.JPG

Img : 027.JPG


Img : 028.JPG

Img : 026.JPG

Img : 027.JPG