Riparian Management and Natural Function of Small Streams in the Northern Interior of British Columbia

Course Manual

March 2007

FIA
Forest Investment Account
Forest Science Program

FOREST SERVICE
NORTHERN INTERIOR FOREST REGION

Fisheries and Oceans Canada
Pêches et Océans Canada

P. Beaudry & Associates Ltd.

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FOREST SERVICE
NORTHERN INTERIOR FOREST REGION

Tour Guide

How

Who

What

Why

When

Outline

- **Who:** Introductions
- **What:** Course objectives and definitions
- **How:** Experiences in small streams and the Prince George DM Project
- **Why:** Effective resource management & legislative requirements
- **When:** Agenda

Introductions

Today's speakers:

- Pierre Beaudry – Pierre Beaudry & Associates (PBA)
- Erland MacIsaac – Department of Fisheries and Oceans (DFO)
- John Rex – Ministry of Forests & Range (MOFR)

- Other project members include:
  - Leisbet Beaudry (PBA) ,
  - Herb Herunter (DFO),
  - Dave Maloney (MOFR)

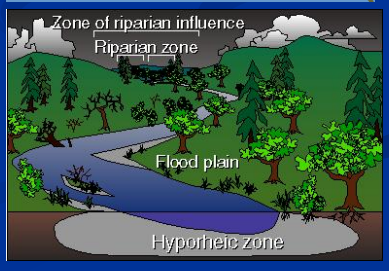
Who are you?

Course Objectives

- We have three primary course objectives:
  - Demonstrate current knowledge of small stream functions and riparian management in the northern interior of B.C.
  - Review concepts about the ecology and function of headwater streams based on current literature and recent research projects.
  - Provide you with an assessment of the Prince George District Manager's Policy on Small Stream Riparian retention, including management considerations.

Small Streams and Riparian Zones

- Small streams: an active channel width <2m, they are important because:
  - The most common channel type,
  - Their aggregate characteristics determine downstream conditions.
- Riparian area: area adjacent to a water-body.



Prince George DM Policy

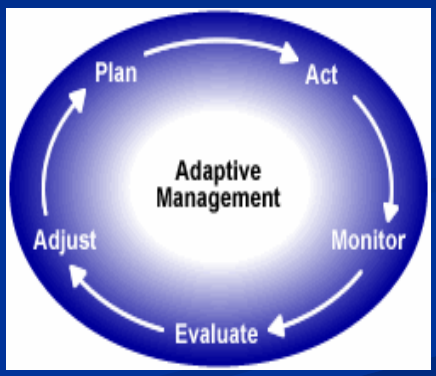
- FPC- No prescribed retention zone on S4, S5, or S6 streams only a riparian management zone.
- The PG DM provided five riparian management objectives, namely :
  - Maintaining 50 to 70% of the natural shade levels,
  - Maintaining adequate long and short-term supply of large woody debris (LWD),

Prince George DM Policy

- Maintaining natural root structure adjacent to streams particularly to minimize soil disturbance within 5m of the stream channel,
- Not overloading stream with fine organic debris,
- Concentrating retention (both patch and single tree) in the 10-15m closest to the stream.

PG Small Streams Project

- Project was initiated in 2000 with funding from FRBC and has continued under FIA-FSP.
- Adaptive management based project started with applying the minimums



Study Areas

- Three locations in the Prince George District:
  - Chuchinka- study and control stream
  - Bowron - two study and control streams
  - Tagai - two study and one control stream
- Synoptic study areas

Tagai, Bowron, and Chuchinka

- BEC zone - SBSdw2
- Tag-13 Active stream width 0.8m, gradient 3%. Tag 12 1.1m, 5%
- Elevation: 900-1000m
- Aspect: NE
- Tag 13-March 2004 Tag-12 July 2004 - BCTS (operator)

- BEC zone - SBSvk
- Active stream width 1m, gradient 4%
- Elevation: 900-920m
- Aspect: NW
- December 2002 - BCTS (operator)

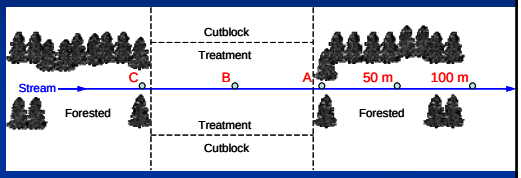
- BEC Zone: SBSwk1
- Active stream width 0.9m, Gradient 1%
- Elevation:780-820m.
- Aspect: SW
- July 2003- Canfor

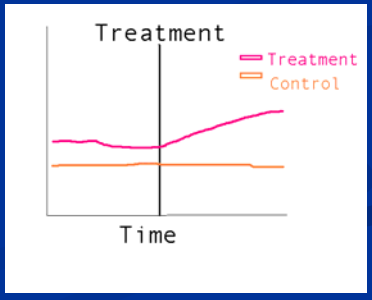
Project Components

Agency	Project Duties
Department of Fisheries and Oceans	Water Quality and Quantity Biological productivity (Primary and Secondary) Fisheries Surveys
Pierre Beaudry & Associates	Channel Morphology (LWD/Erosion) Riparian Tree Inventory Angular Canopy Densiometer
Ministry of Forests and Range	Air and Stream Temperature Groundwater Addition Project Management

Study Design

- The project employs a BACI-PS design.
  - Treatment data are compared to spatial controls before during and after the activity of interest.
- 2-3 years of pre-harvest data and 2-3 years of post-harvest data



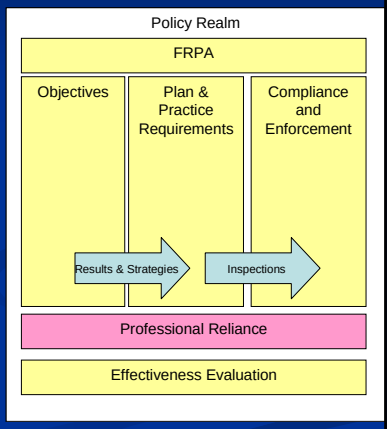


Our Goal

- To provide information that can enhance management of these resources:
- Extension products are a key deliverable:
  - Course and Field Tours
  - **Web page : www.for.gov.bc.ca/hre/ffip**
  - Extension notes
  - Journal articles
  - Synthesis report due out next year

Why

- FPC – District policy was developed to address a management issue.
- FRPA: Results based code-professional reliance and due diligence… keeping up to date with current knowledge. On the ground practice and generation of FSPS.
  - Section 8, Section 52(2)

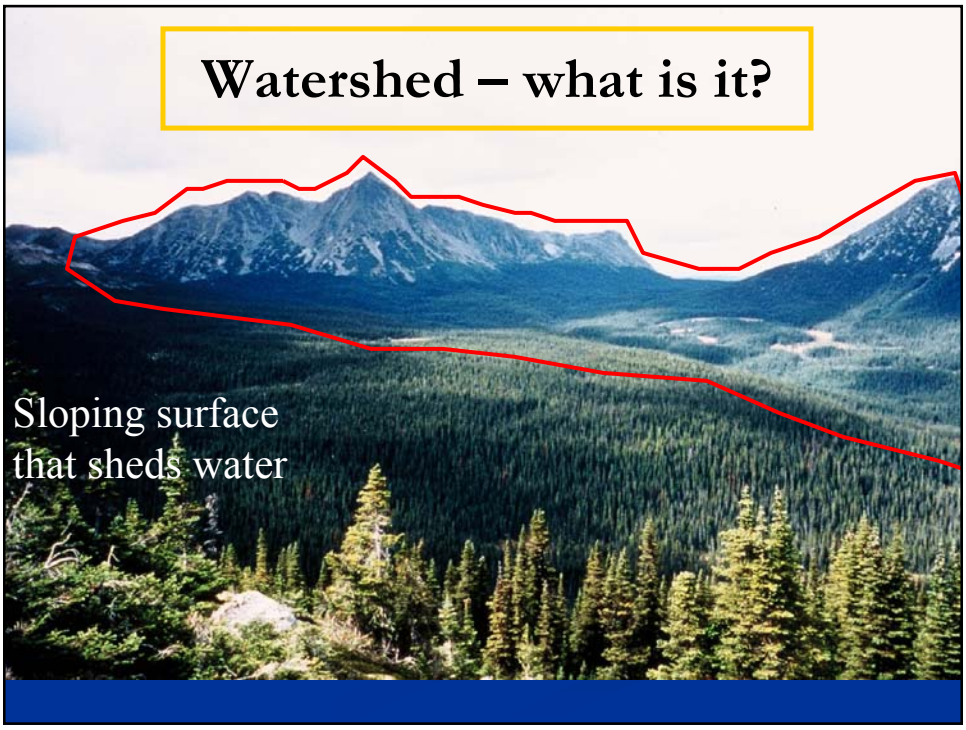


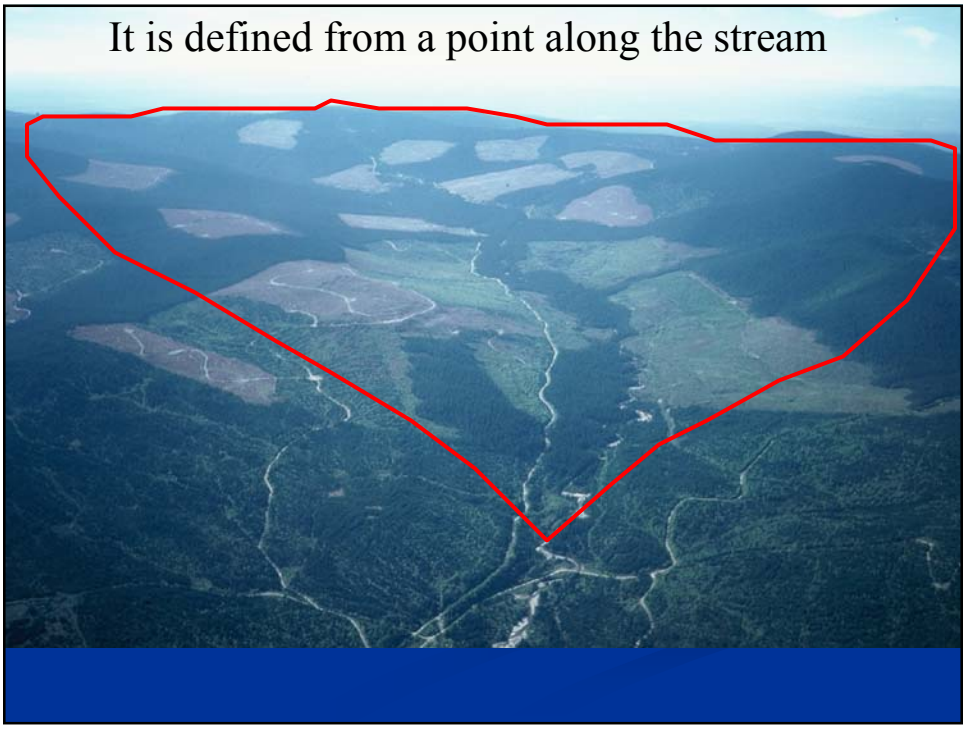
Agenda

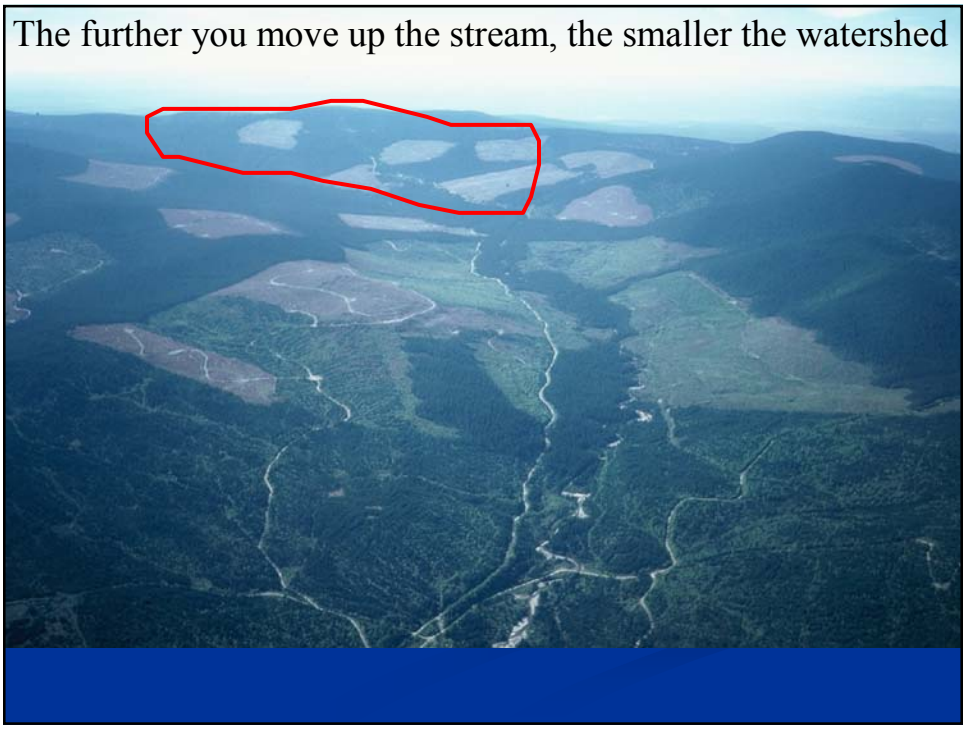
- 08:30 - 09:00 Introduction
  09:00 - 09:30 Streamflow (PBA)
  09:30 – 10:00 Sediment Dynamics (PBA)
  Coffee Break
- 10:20 - 11:20 Water Quality (DFO)
  11:20 - 12:00 Shading and Temperature (MOFR)
  Lunch
- 13:00 - 13:45 Woody Debris and Channel Morphology (PBA)
  13:45 - 15:00 Biological Components (DFO)
  Coffee Break
- 15:20 - 15:40 Discussion Group
  15:40 - 16:20 Management Implications and Discussion (PBA + Panel)
  16:20 - 16:30 Closing Comments and Course Evaluation

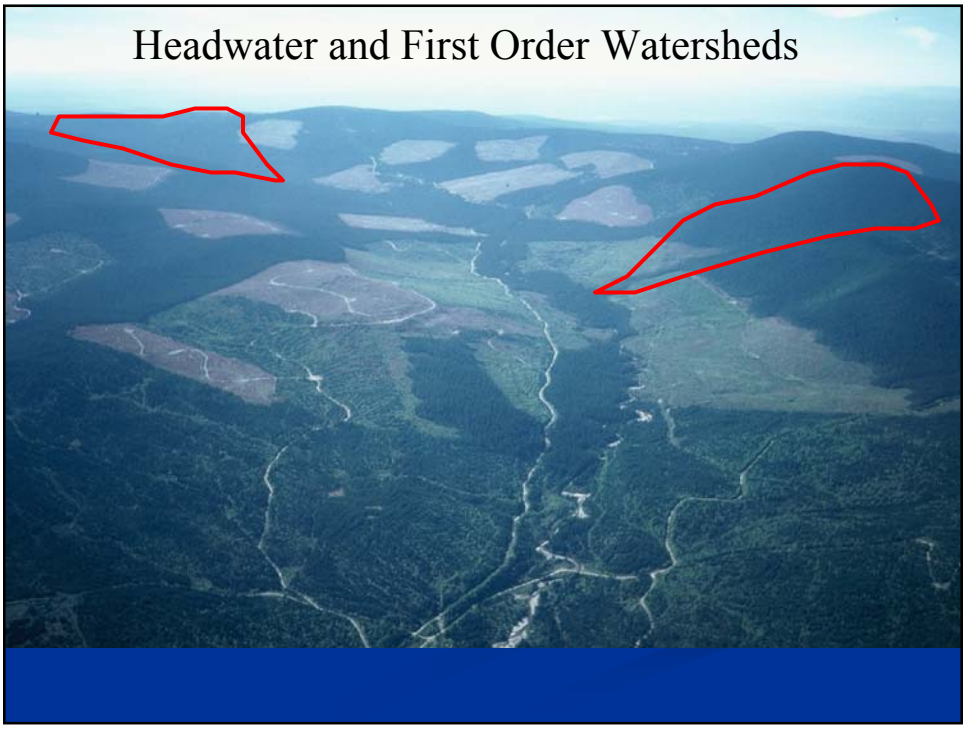
Watersheds and Streamflow

Watershed – what is it?



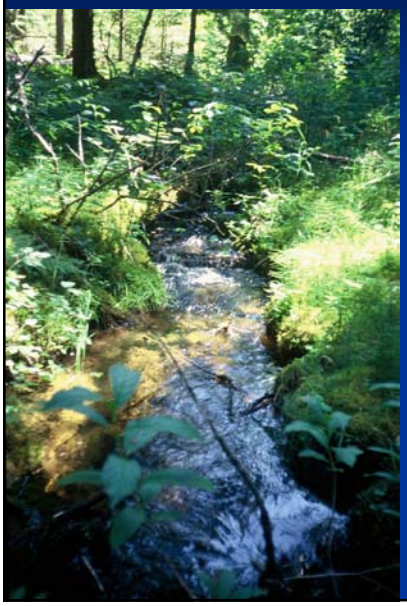

It is defined from a point along the stream

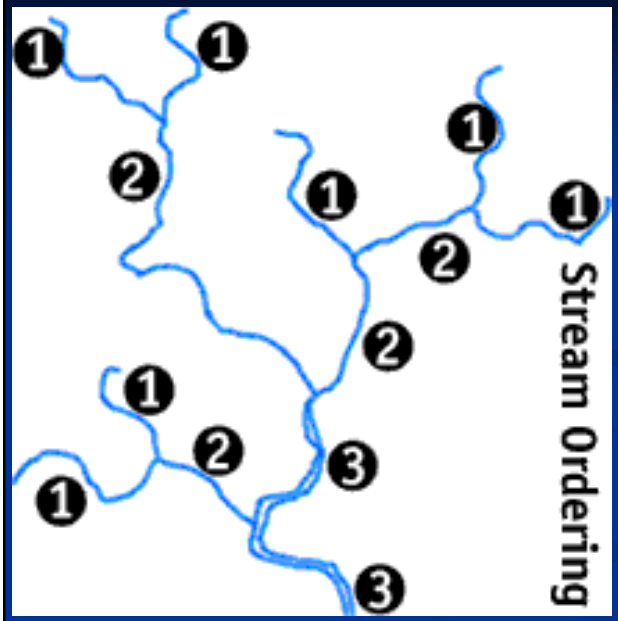

The further you move up the stream, the smaller the watershed



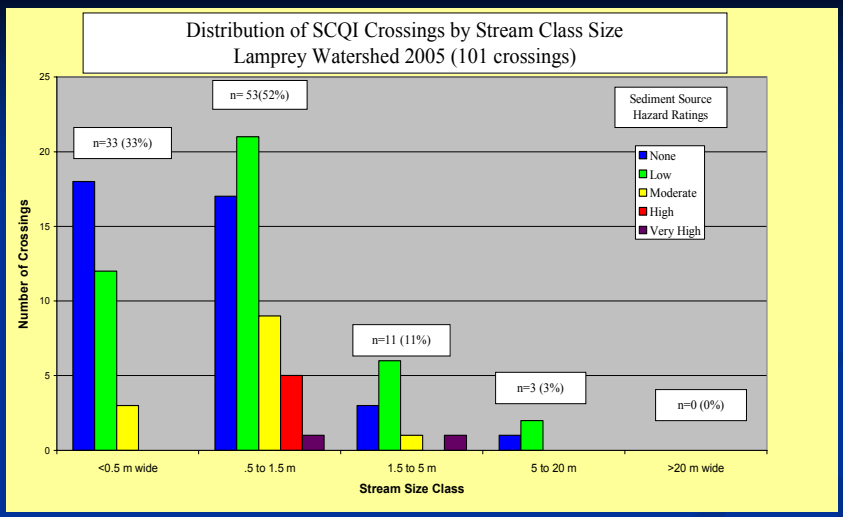
The effects of many disturbance activities in a watershed can be concentrated through the stream network and result in negative cumulative downstream impacts

Watershed Cumulative Impacts are usually most detectable in headwater streams





The headwater, or low order streams is what this course/workshop focuses on.



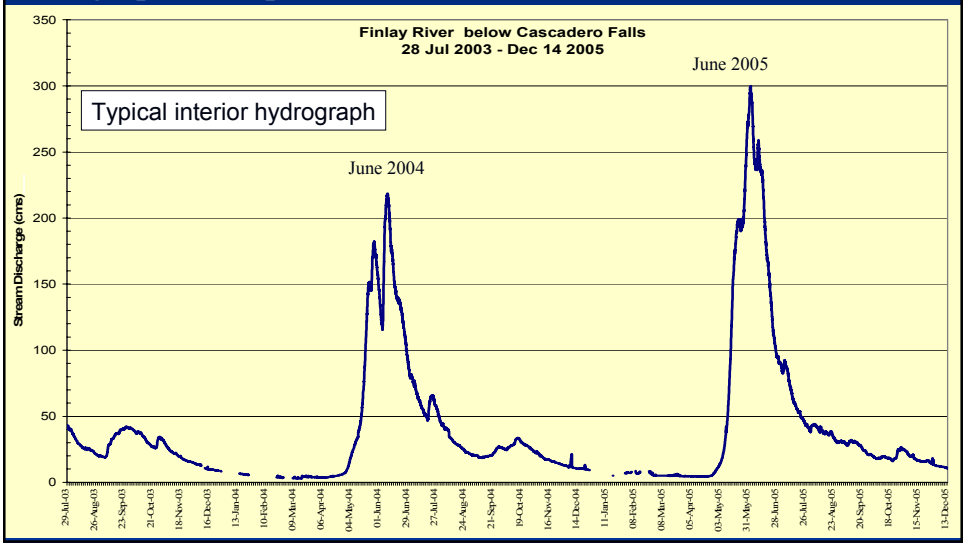
Abundant data from the central interior clearly show that small streams dominate the landscape and may be the most vulnerable to land use impacts.

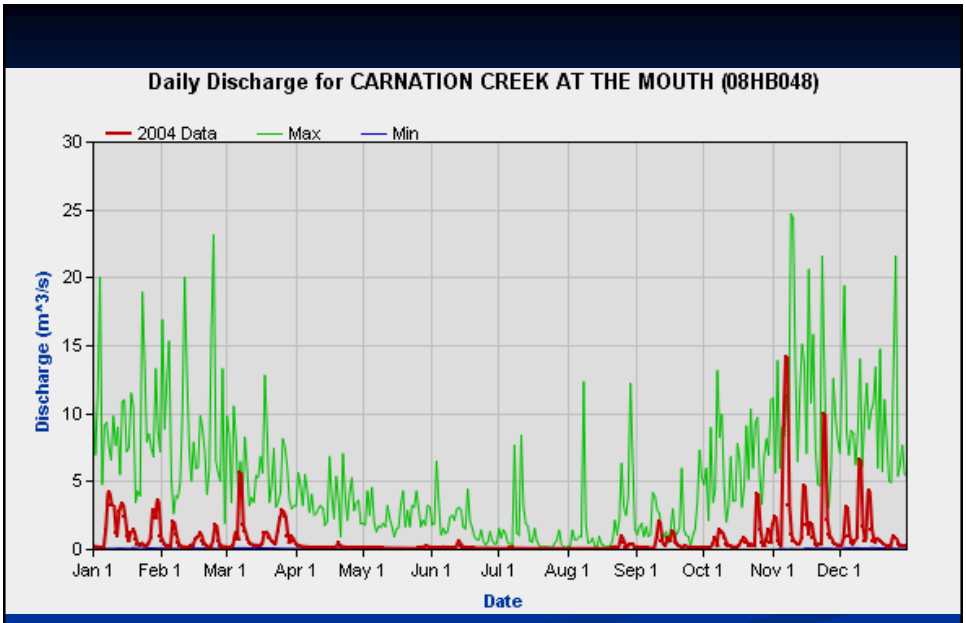
WHAT IS STREAMFLOW?

- It is the total volume of water flowing in a stream channel at a given point (e.g. watershed outlet)
- It is measured as a volume per unit time (cubic metres per sec)

WHAT IS A HYDROGRAPH?

A graphical representation of streamflow over time

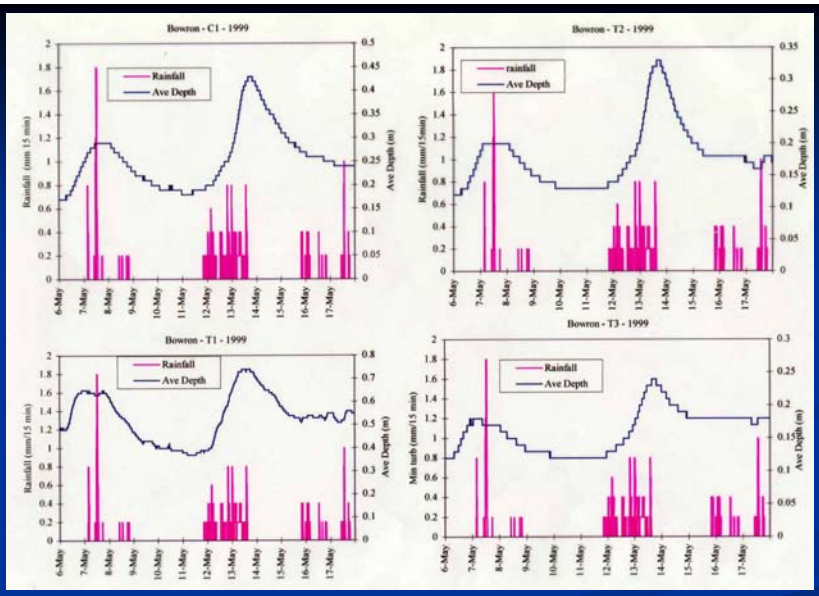




Coastal Hydrograph

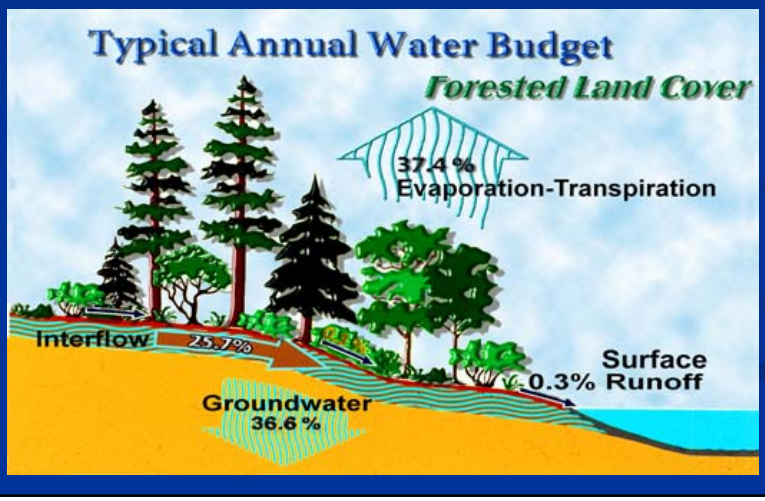
Streamflow Characteristics of Headwater (or low order) Watersheds

- Respond very quickly to precipitation events.
- Hydrograph rises and falls very quickly
- Other variables also respond very quickly (e.g. temperature, turbidity etc)
- This tends to make them sensitive to disturbances within the watershed.

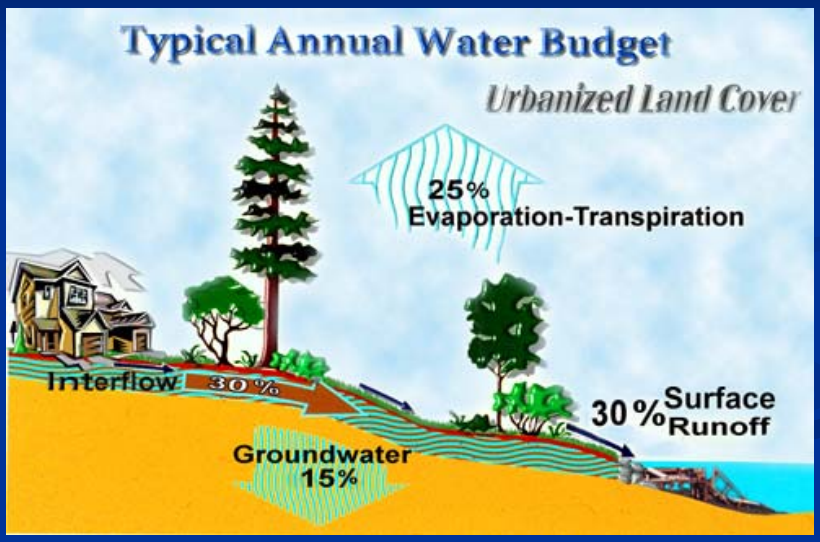


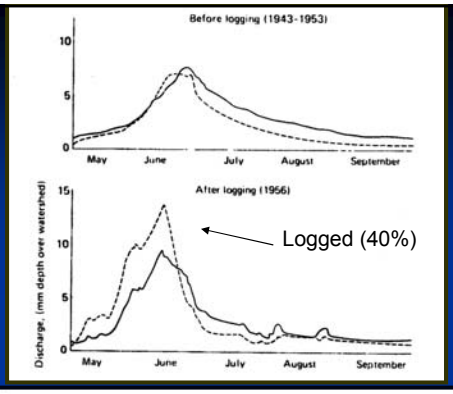
Streamflow response is usually very rapid in small forested watersheds

A significant amount of water is used by the trees and lost to evaporation. A large amount of water infiltrates into groundwater and very little runs over the surface.

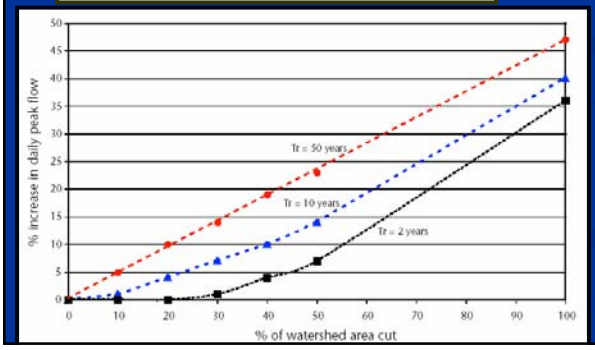


When trees in a watershed are removed and roads and ditches are built, that results in increased water flow to the streams – i.e. the water budget is changed.





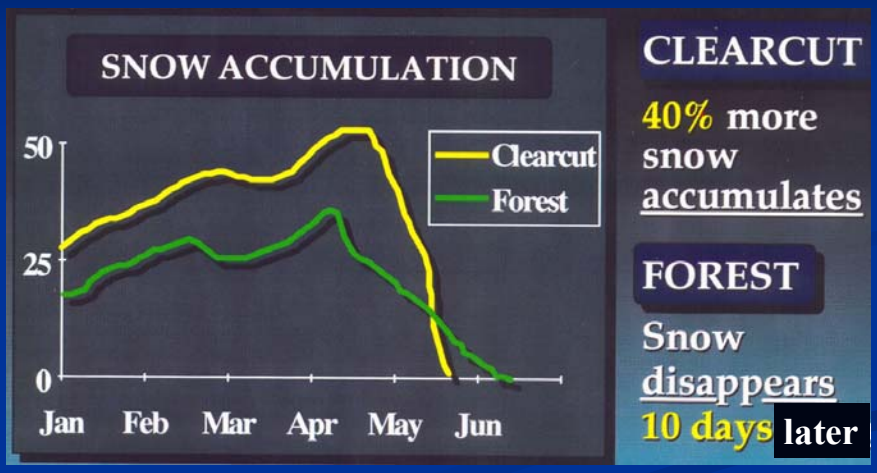
Results from the Fool Creek experimental watershed Colorado



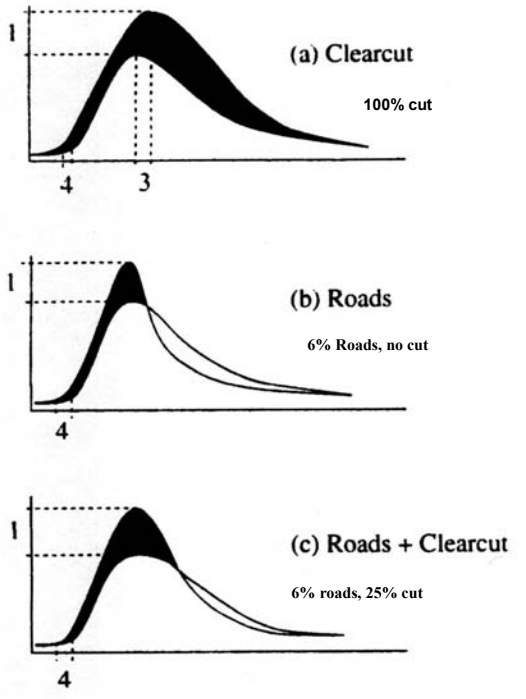
Results modeled using Upper Penticton Creek watershed data

(Schnorbus et. al. 2004

Effects of forest removal on snow accumulation and melt rates

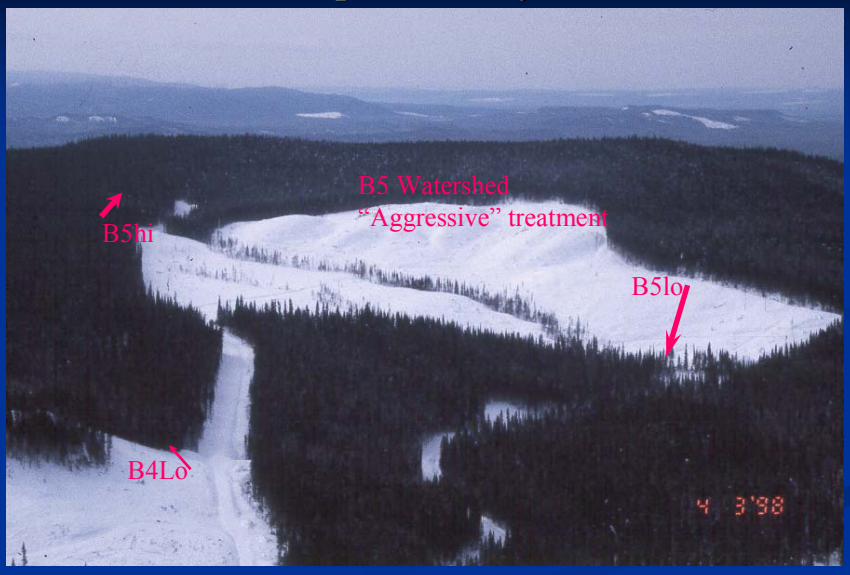


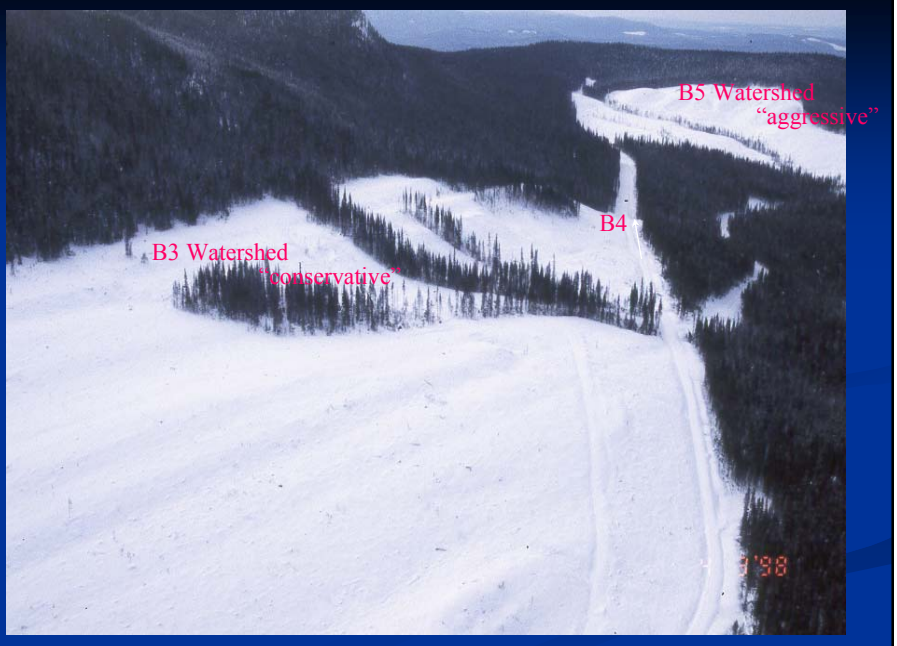
"Interior" Process



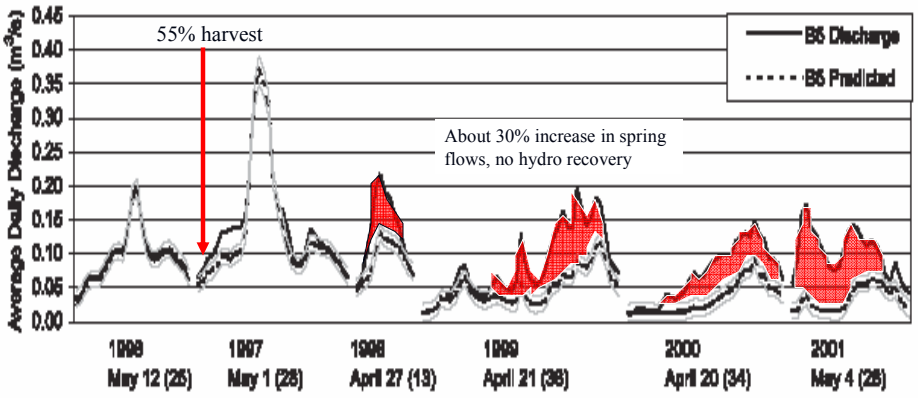
Changes to peak discharges after forest harvesting operations (Jones and Grant)

Baptiste Study



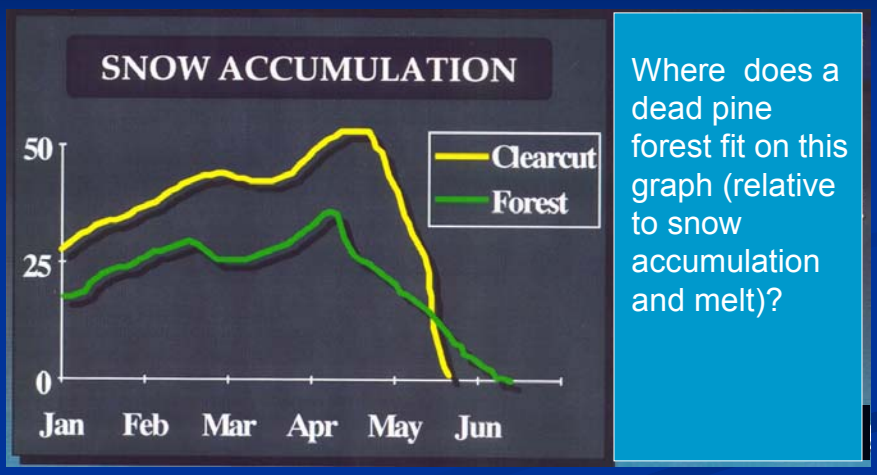


Increase in spring flow after harvest – Baptiste B5



Macdonald, Beaudry, MacIssac, Herunter, CJFR 2003

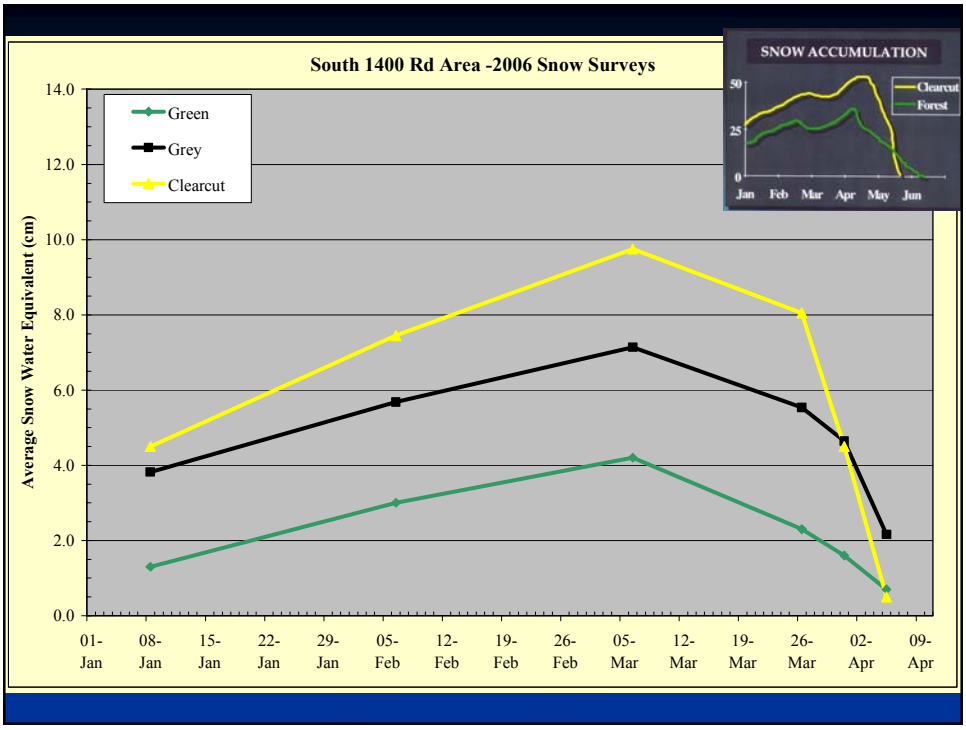
What about Effects of Mountain Pine Beetle on snow accumulation and melt rates?

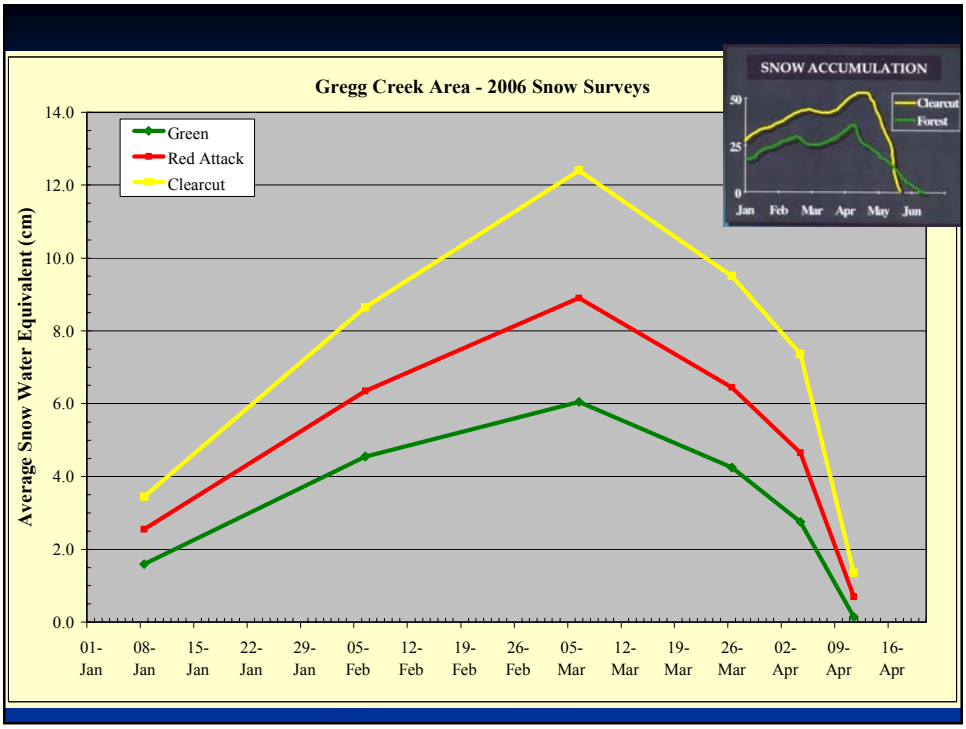


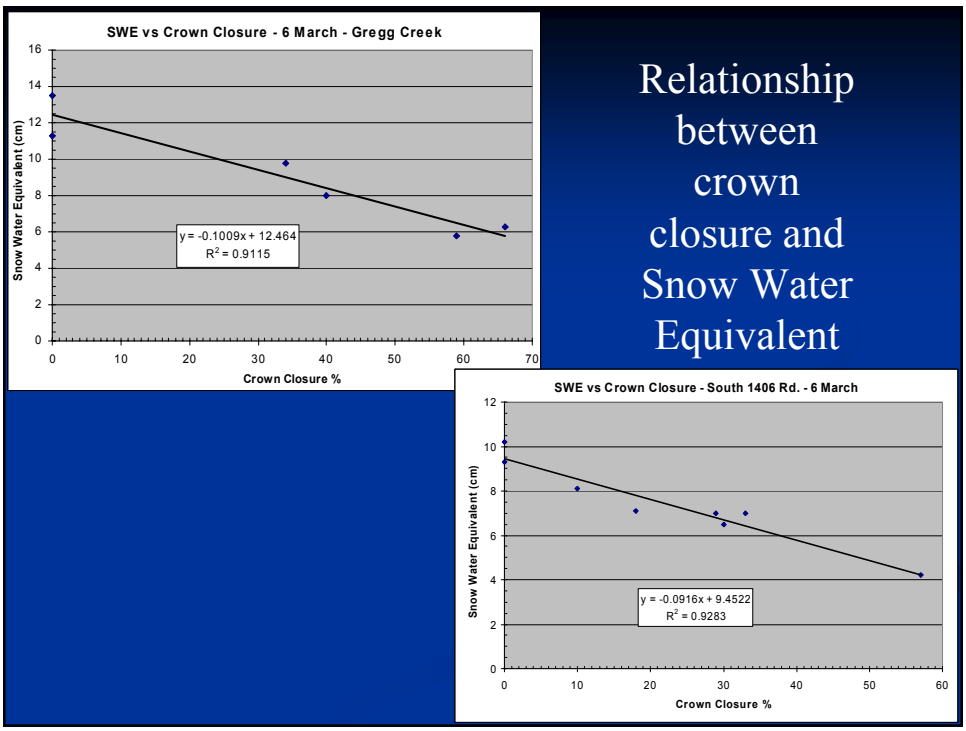
Where does a dead pine forest fit on this graph (relative to snow accumulation and melt)?

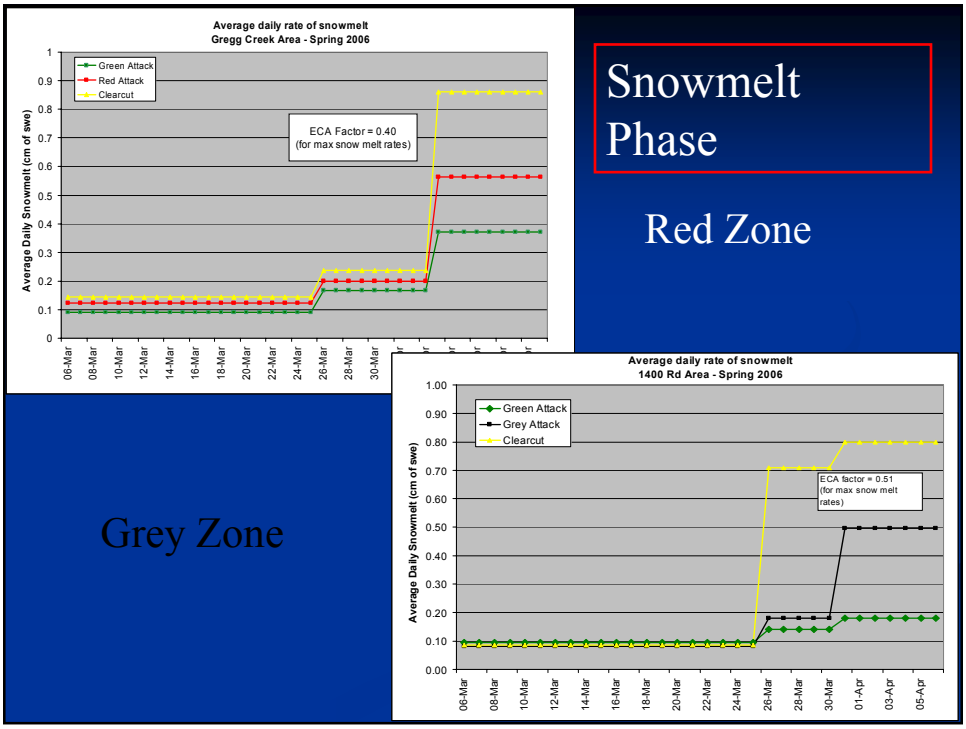
"Interior" Process

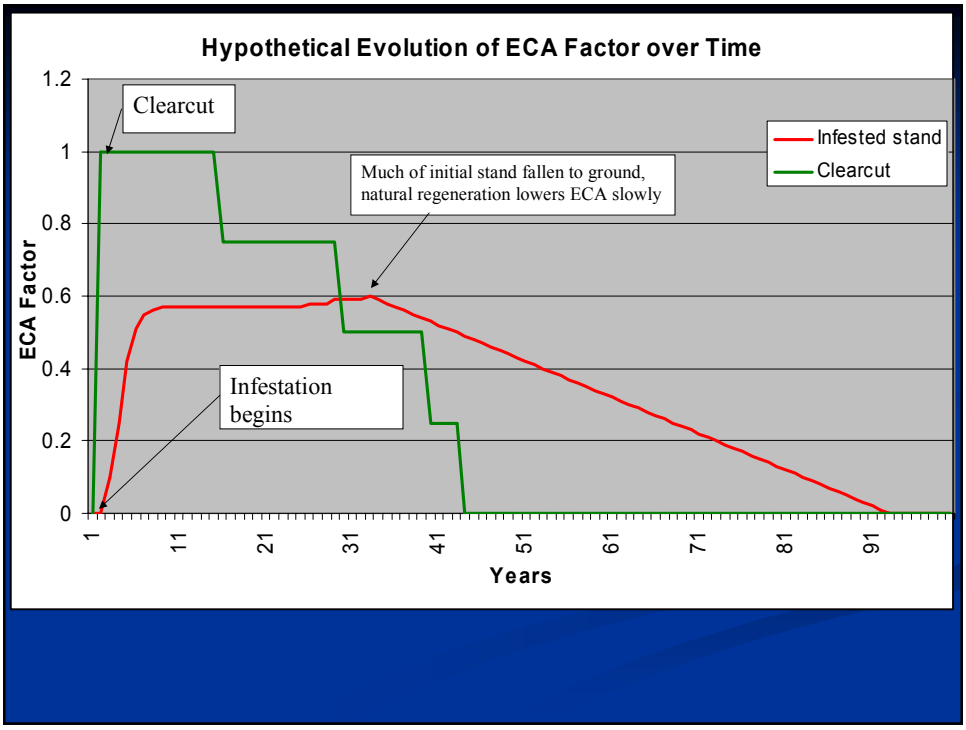
Snow surveys are being conducted in 20 pine stands south of Vanderhoof (Timber supply block F) in 2006 and 2007.




Gregg Creek Area - 2006 Snow Surveys
Average Snow Water Equivalent (cm)
Green
Red Attack
Clearcut
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
01-Jan
08-Jan
15-Jan
22-Jan
29-Jan
05-Feb
12-Feb
19-Feb
26-Feb
05-Mar
12-Mar
19-Mar
26-Mar
02-Apr
09-Apr
16-Apr
SNOW ACCUMULATION
Clearcut
Forest
50
25
0
Jan
Feb
Mar
Apr
May
Jun

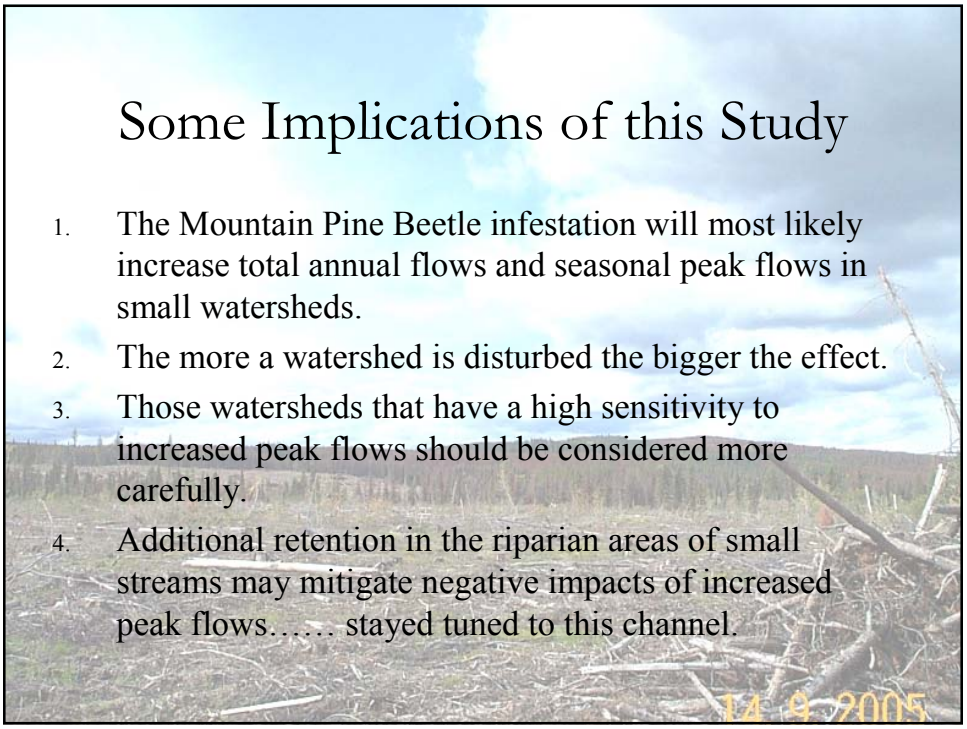

SWE vs Crown Closure - 6 March - Gregg Creek
Snow Water Equivalent (cm)
y = -0.1009x + 12.464
R² = 0.9115
Crown Closure %
Relationship between crown closure and Snow Water Equivalent
SWE vs Crown Closure - South 1406 Rd. - 6 March
Snow Water Equivalent (cm)
y = -0.0916x + 9.4522
R² = 0.9283
Crown Closure %


Average daily rate of snowmelt
Gregg Creek Area - Spring 2006
Green Attack
Red Attack
Clearcut
ECA Factor = 0.40
(for max snow melt rates)
Average Daily Snowmelt (cm of swe)
Snowmelt Phase
Red Zone
Grey Zone
Average daily rate of snowmelt
1400 Rd Area - Spring 2006
Green Attack
Grey Attack
Clearcut
ECA factor = 0.51
(for max snow melt rates)
Average Daily Snowmelt (cm of swe)


Hypothetical Evolution of ECA Factor over Time
Clearcut
Much of initial stand fallen to ground, natural regeneration lowers ECA slowly
Infested stand
Clearcut
Infestation begins
ECA Factor
Years

Some Implications of this Study

1. The Mountain Pine Beetle infestation will most likely increase total annual flows and seasonal peak flows in small watersheds.
2. The more a watershed is disturbed the bigger the effect.
3. Those watersheds that have a high sensitivity to increased peak flows should be considered more carefully.
4. Additional retention in the riparian areas of small streams may mitigate negative impacts of increased peak flows…… stayed tuned to this channel.



Some Implications of this Study

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Take Home Message: Low Order Watersheds and Streamflows

Takla research watershed

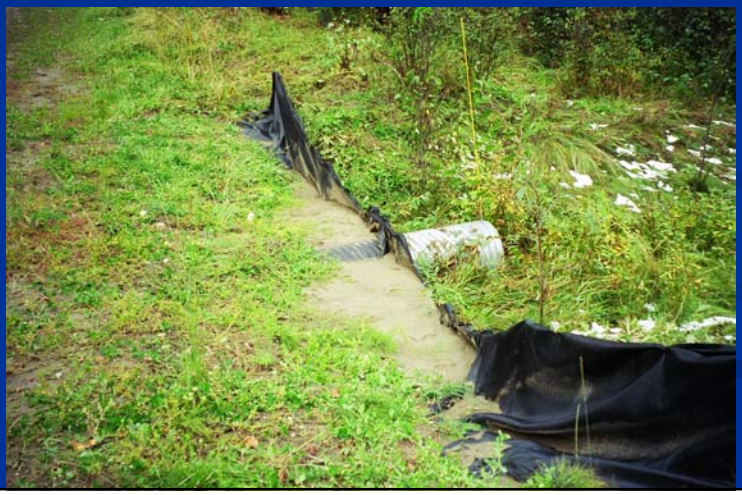
- Easy to harvest a large percentage of a small watershed
- These are the "feeder" streams for downstream organisms and processes (river contiuum)
- In the central interior, much of the disturbances occur in headwater watersheds

Take Home Message: Low Order Watersheds and Streamflows

Takla research watershed

- It is relatively easy to impact processes because streams are small and flows volumes are low
- These small streams are NOT ditches, they are Very important component of larger watersheds

Sediment and Small Streams



Sediment Concerns

- Water quality – domestic and industrial use
- Channel aggradation, pool depth
- Channel stability
- Algae survival
- Macroinvertebrate survival and species shift
- Survival, emergence and growth of salmonids
- Impacts on visual feeders

Sediment the Paradox

- Sediment is an essential element for virtually all streams. It is not an inherently toxic substance.

"Sediment" Includes:

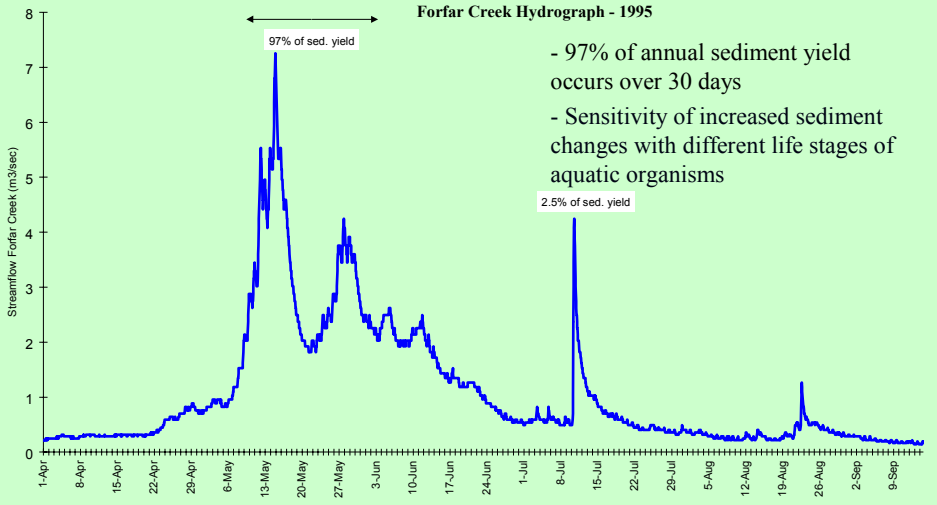
-coarse particles bounced along the bottom (bedload)

- Fine particles carried in suspension (suspended sediment)

Sediment the Paradox

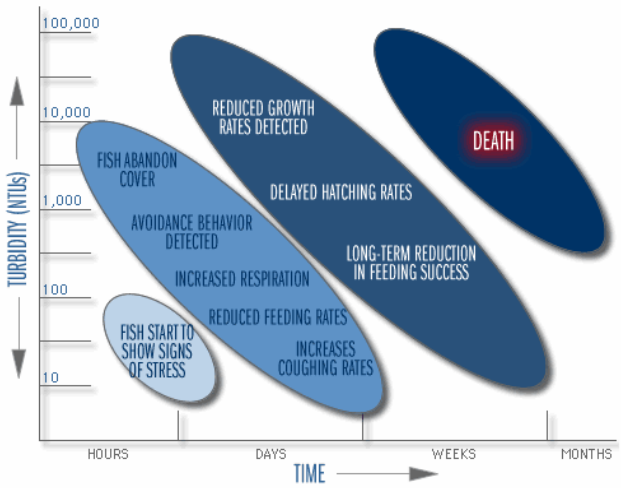
- There is a broad middle ground between too much and too little sediment in small stream ecosystems.
- The quantity, frequency and timing of sediment delivery are important

Timing of Sediment Input



- 97% of annual sediment yield occurs over 30 days
- Sensitivity of increased sediment changes with different life stages of aquatic organisms

Forfar Creek, May streamflows when 97% of the annual sediment yield occurs (56,000 kg)



Schematic adapted from "Turbidty: A Water Quality Measure", Water Action Volunteers, Monitoring Factsheet Series, UW-Extension, Environmental Resources Center. It is a generic, un-calibrated impact assessment model based on Newcombe, C. P., and J. O. T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management. 16: 693-727.

Sediment impacts can be dependent on:

- Amount
- Duration and
- Timing

Natural Sediment Sources
(DM Policy study streams)

Typically wide disconnected valley flats

- 0 to 3 sediment sources per 50m (predominately rootwads)
- Lacustrine parent material have eroding banks.
- Natural rate of blowdown.

Sediment sources

Pre-harvest Tagai 2001

Post- harvest Tagai 2003

Post-harvest Chuchinka 2003

Post-Harvest Changes in Sediment Sources (DM Policy Study Streams)

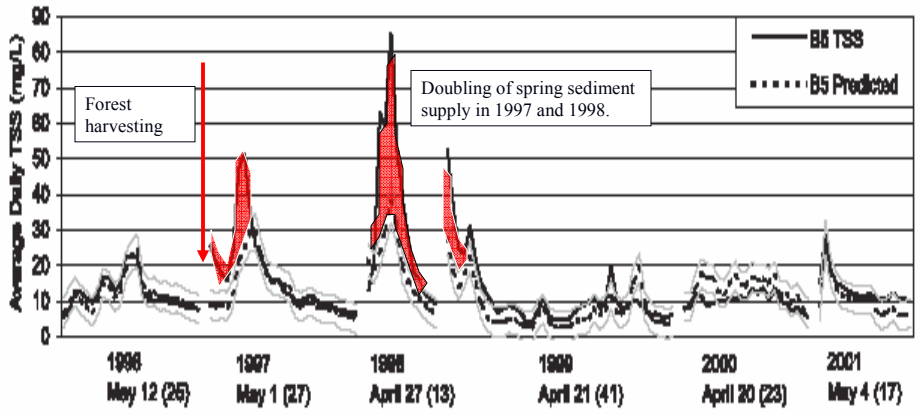
Area	Year	# of sediment sources/50 m
Tagai	2002 pre-harvest	1
	2003 pre-harvest	1
	2004 post-harvest	2.25
	2005 post-harvest	2.25
Chuchinka	2002 pre-harvest	1
	2003 pre-harvest	1
	2004 post-harvest	1
	2005 post-harvest	1
Bowron	2002 pre-harvest	2
	2003 pre-harvest	3
	2004 post-harvest	3
	2005 post-harvest	3.5

All new sediment sources were from blowdown

Post-harvest Changes in Sediment at Baptiste small stream study

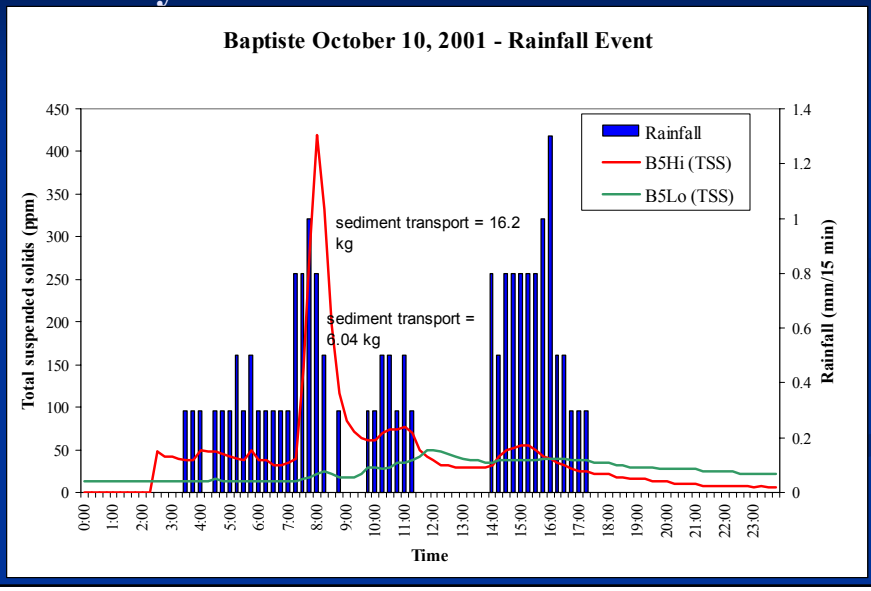
Fairly large accumulations of fine sand were noted post harvest

Increase in suspended sediment – Baptiste small streams



Macdonald, Beaudry, MacIssac, Herunter, CJFR 2003

Increases in Suspended Sediments During Rain only Events



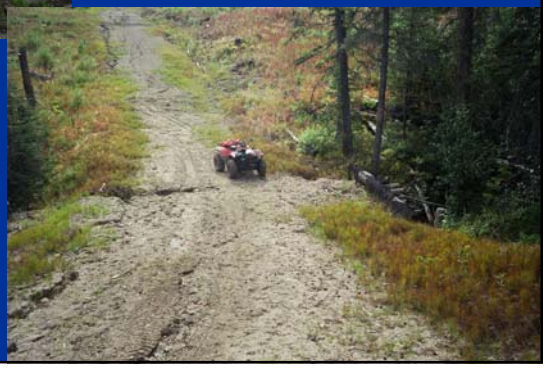
Roads

- Erosion volumes are small but cumulative impacts can be large.
- In small central interior streams, crossings can be the single largest contributor of accelerated sediment
- A recent riparian effectiveness evaluation identified road crossings as having the biggest impact

As part of several sustainable forest management initiatives we have surveyed over 6,500 stream crossings in the Interior of BC and western Alberta to assess the sediment source hazard.

Stream crossings can typically have numerous sources of sediment associated with them

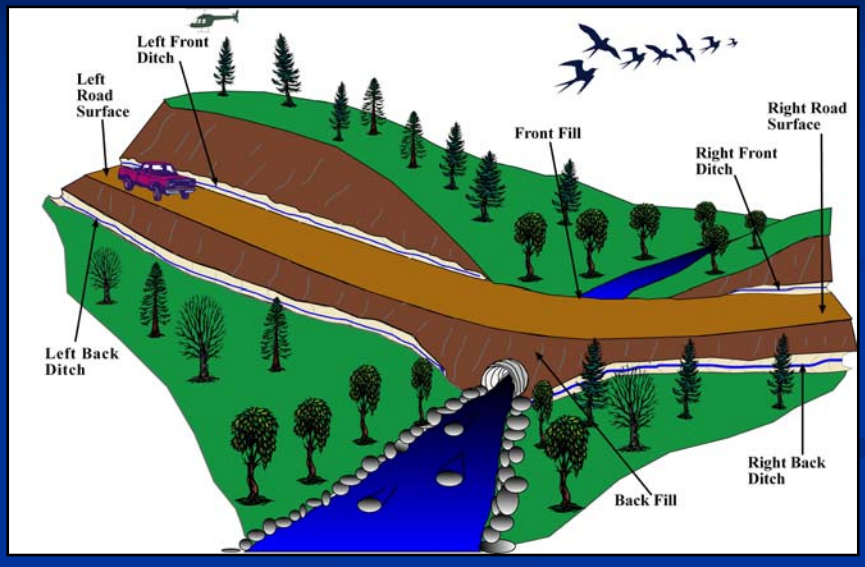
Road running surfaces



Fill slopes

Ditches

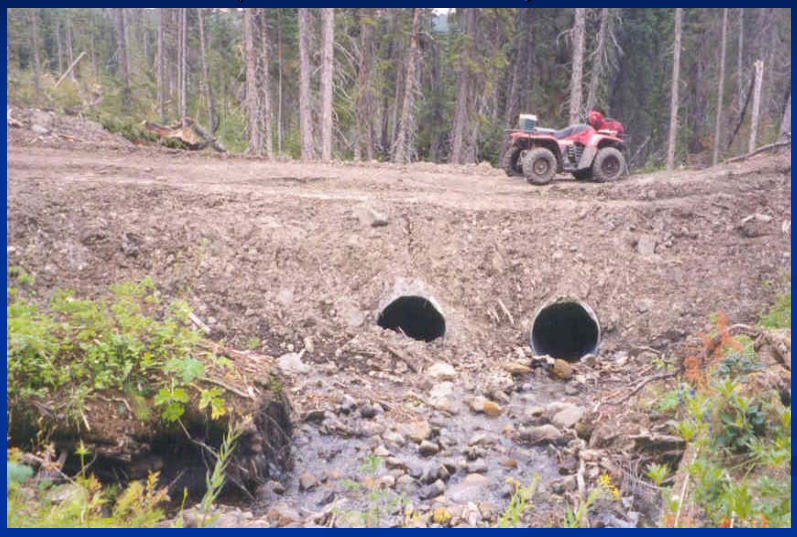
Using a systematic evaluation of the sediment sources, we can score the sediment hazard at a stream crossing



Low Hazard
(Score range 0.1-0.3)

Moderate Hazard
(score range = 0.4 to 0.7)

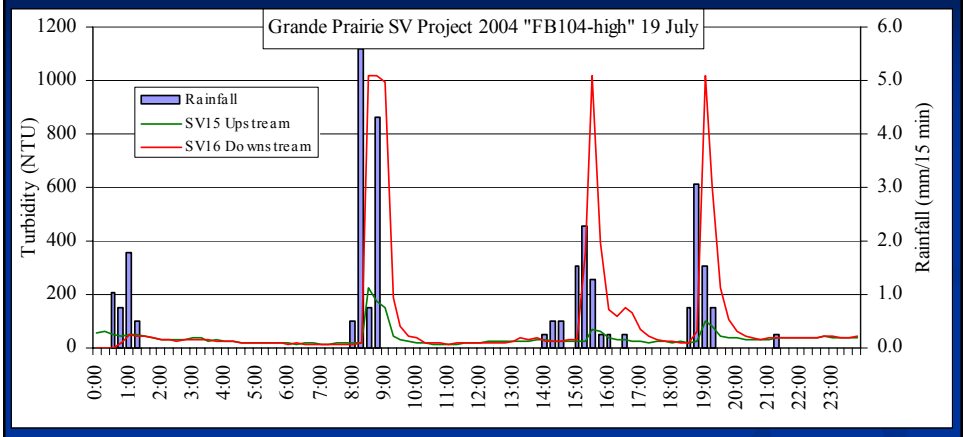
High Hazard
(score 0.8-1.6)



Very High Hazard, score >1.6

Areas dominated by fine soil textures can present very large erosion and sediment delivery challenges

CUMULATIVE EFFECTS OVER TIME



High intensity very short duration impacts – does this have an effect on aquatic resources ??????

New road construction and active hauling.

Good attempt at ESC

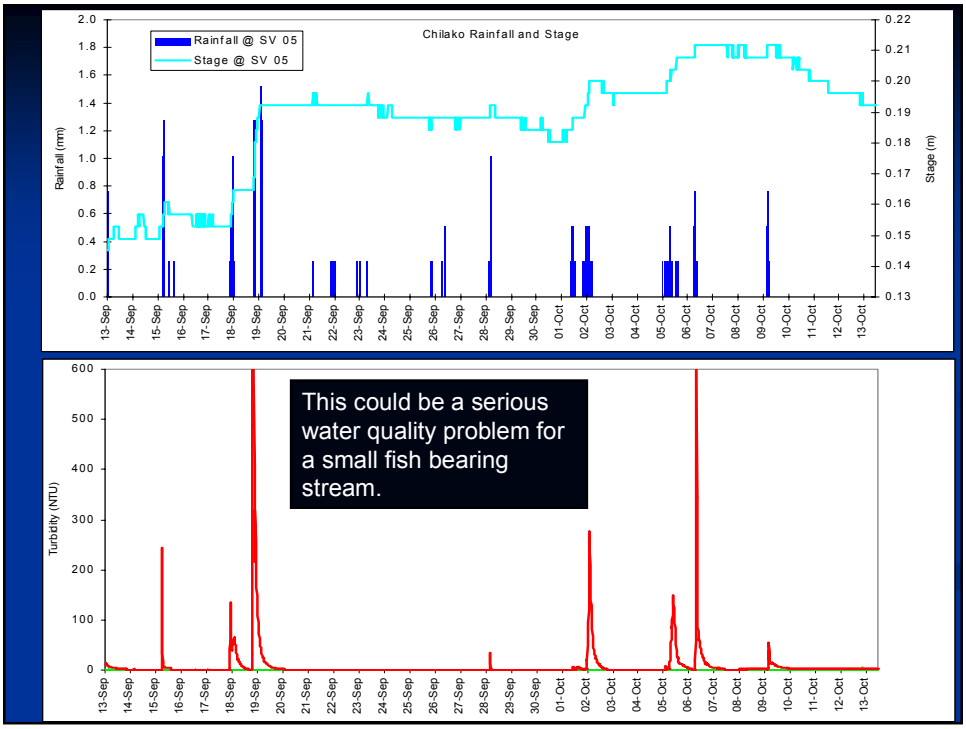


Table xx. Impact assessment model for clear water fishes exposed to conditions or reduced water clarity (from Newcombe 2004).

isual arity of ater NTU[1])	Severity-of-ill effects **Scores** (SEV)										
1100	7	8	9	10	11	12	13	14			
600	7	7	8	9	10	11	12	13	14		
400	6	7	7	8	9	10	11	12	13	14	
230	4	5	6	7	8	9	10	11	12	13	14
150	3	4	5	6	7	8	9	10	11	12	13
75	2	3	4	5	6	7	8	9	10	11	11
55	1	2	3	4	5	6	7	8	9	10	10
30	0	1	2	3	4	5	6	7	8	9	9
20	0	0	1	2	3	4	5	6	7	8	8
12	0	0	0	1	2	3	4	5	6	6	7
7	0	0	0	0	1	2	3	4	4	5	6
5	0	0	0	0	0	1	2	3	4	4	5
3	0	0	0	0	0	0	1	2	3	4	5
2	0	0	0	0	0	0	0	1	2	2	3
1	0	0	0	0	0	0	0	0	0	1	2
	1	3	7	1	2	6	2	7	4	11	30
	Hours			Days			Weeks		Months		
	Net Duration of Exposure										

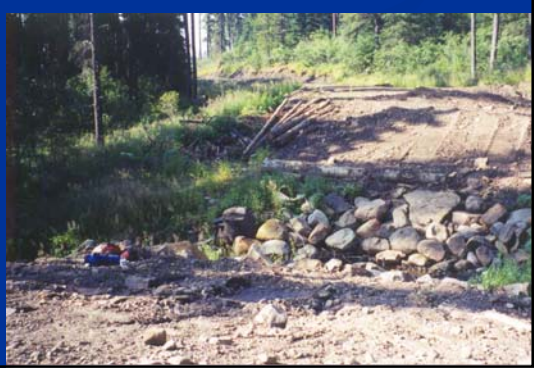
Note: The SEV impact assessment is based on *net* duration (less clear-water intervals) and weighted-average visual clarity. Recurrent events sum when integrated over relevant intervals

[1]. NTU is the Nephelometric turbidity unit, which is a measure of light scattering by suspended clay particles and is directly related to water clarity.

In summary:

1)Riparian treatments are typically not a problem for sediment delivery when an effective machine free zone is maintained

2) Road crossings, however can potentially be a significant source of accelerated sediment delivery to small streams.



3) Erosion and sediment control efforts must recognize the importance of small streams in the landscape

Possible Mountain Pine Beetle Implications to the issue of sediment and small streams

1. Increased flows <u>can</u> cause accelerated bank erosion and thus could alter the sediment supply (depends of stream sensitivity)
2. More active roads, means more active crossings and thus potentially increased sediment supply.
3. More aggressive riparian salvage treatments = ?????????

Prince George Small Stream Riparian Buffers Study

Riparian Management and the Water Quality of Headwater Streams

Erland MacIsaac, Science Branch, Fisheries and Oceans Canada
School of Resource & Environmental Management, Simon Fraser University

Fisheries Objectives for Sustainable Forestry Management of Headwater Streams

- Maintain water quality (e.g. temperature, oxygen, suspended sediment, nutrients, water chemistry)
  - Retain shade, manage road crossings, manage organic debris loads, minimize watershed soil disturbances
- Maintain physical habitat (e.g. pools, cover, undercuts, spawning gravels)
  - Retain large woody debris inputs and streambank trees, minimize new sediment sources
- Maintain stream productivity (e.g. litterfall, invertebrates, periphyton, fish)
  - Management currently hampered by inadequate knowledge

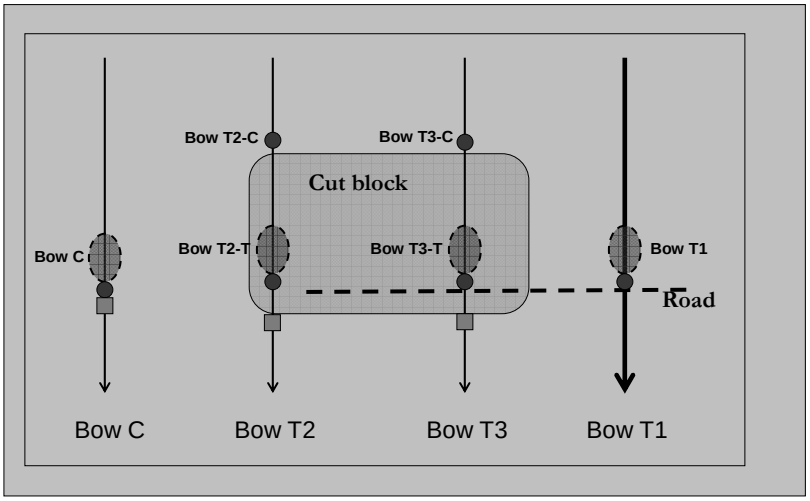
Maintain Water Quality of Headwater Streams

- Water chemistry
  - Inorganic nutrients (Nitrogen & Phosphorous)
  - Dissolved organic matter
- Suspended sediment (turbidity/discharge)
- Water temperature (John Rex)

Effects of Riparian and Watershed Processes on Water Chemistry

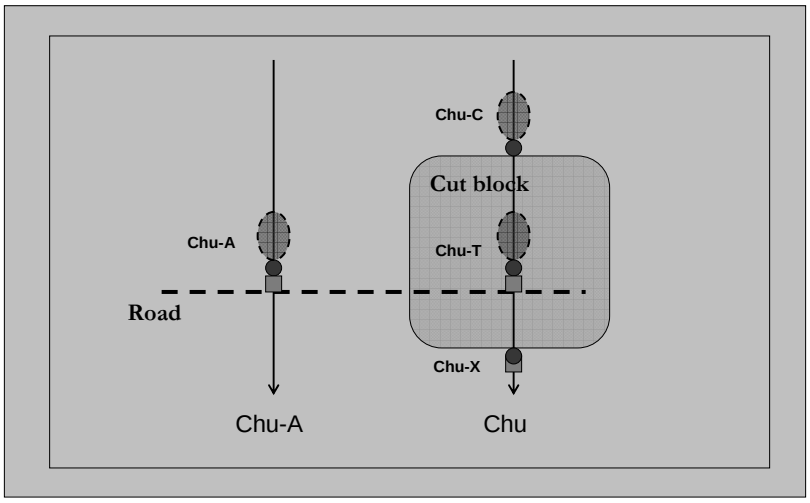
- "Logging increases ion flux from the watershed"
- Stream nutrients, dissolved organics and ion chemistry largely determined by watershed processes
  - Soil chemistry and disturbance
  - Reduced vegetation uptake
  - Groundwater versus soil-water sources
- Large riparian buffers may moderate land-use effects on stream water chemistry (e.g. agriculture)
- Effects of forest harvesting on stream water chemistry are mixed and site dependent (Feller 2005 JAWRA)

Site Schematic – Bowron Sampling Stns



Water sampling stn Turbidity/discharge stn Sampling reach

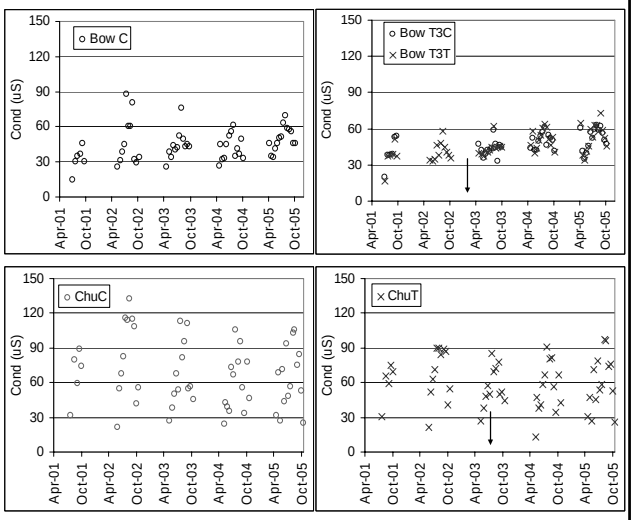
Site Schematic – Chuchinka Sampling Stations



Water sampling stn Turbidity/discharge stn Sampling reach

Specific conductance

- **Total ion content of water (groundwater generally higher than soil water)**
- **Peaks during low summer flow (more groundwater influence)**
- **No significant changes after harvesting**

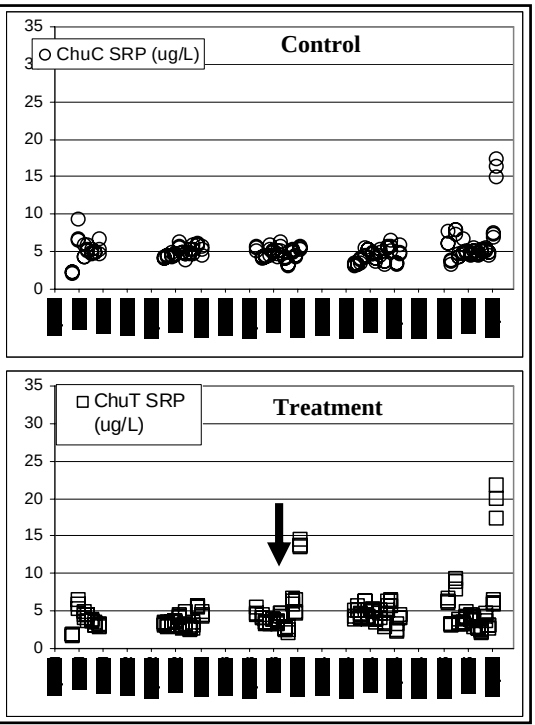


Stream Nutrients

- **Inorganic Nitrogen and Phosphorous**
  - **periphyton (algae) production**
  - **fungi and bacteria: N & P enhance litter breakdown and food quality for aquatic invertebrates**

Example:
Chuchinka streams: Soluble Reactive Phosphorous (SRP)

- **Primary nutrient for periphyton, microbial communities**
- **No significant changes after harvesting**
- **Levels of nutrients in these headwater streams very low**



Nutrient and water chemistry changes after harvesting

Chemical Constituent	Bowron	Chuchinka
Inorganic Nitrogen (nitrate/ammonium)	No Change (1 – 400 ug N/L)	No Change (1 – 100 ug N/L)
Dissolved Phosphorous (inorganic + organic)	No Change (2.0 – 7 ug P/L) *	No Change (5 – 20 ug P/L) *
Dissolved Inorganic P (soluble reactive P)	No Change (<0.2 – 3 ug P/L) *	No Change (0.2 – 6 ug P/L) *
Specific Conductance	No Change (30 - 120 uS)	No Change (30 – 90 uS)

* Dissolved phosphorous very low for aquatic habitats

Water Chemistry

- No significant changes in stream nutrient levels or ion content 2.5-3 years after logging
- DM Policy riparian prescriptions likely had little influence on water chemistry
- Watershed processes likely dominate:
  - % of watershed harvested and vegetation regrowth
  - surficial geology and soil processes
  - degree of soil disturbance and hydrologic changes
- Very low phosphorous levels have implications for stream productivity

Stream Dissolved Organic Matter

- Dissolved organic matter (DOM)
  - nutrient for bacteria biofilms
  - nature's Ultraviolet Radiation (UVR) sunscreen
- Watershed soil processes determine DOM levels leaching to streams

DOM and Ultraviolet Radiation (UVR)

UVR affects all biota

Photo: Max Bothwell

Effects of UV Radiation on Behaviour, Physiology, and Development of Juvenile Coho

Max Bothwell, Blair Holtby, et al. unpublished

- actively avoid UVR; may limit foraging time
- fish fatty-acid changes indicate stress
- lower burst swimming speeds
- growth rates and condition factors lower
- high fin fraying from nutrition or hormone problems

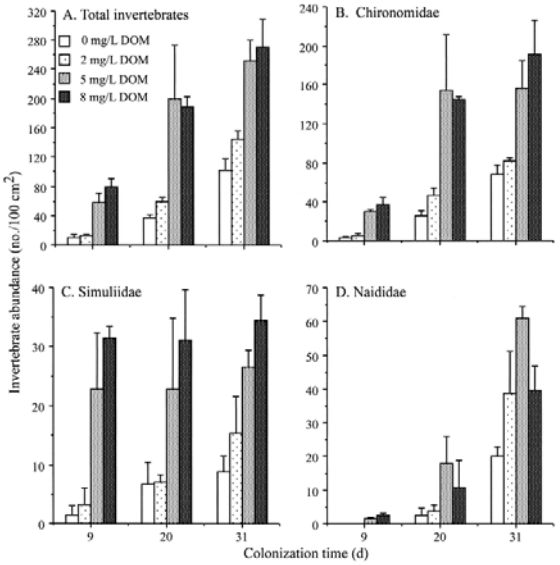
Direct Effects On Fish & Indirect Effects On Foodwebs

Dissolved organic matter (DOM) absorbs UVR in streams

Low level of DOM can expose invertebrate communities to UVR

Colonization rates reduced

Drift rates may increase



Kelly, David J., Clare, John J., Bothwell, Max L.
Attenuation of solar ultraviolet radiation by dissolved organic matter alters benthic colonization patterns in streams
Journal of the North American Benthological Society 2001 20: 96-108

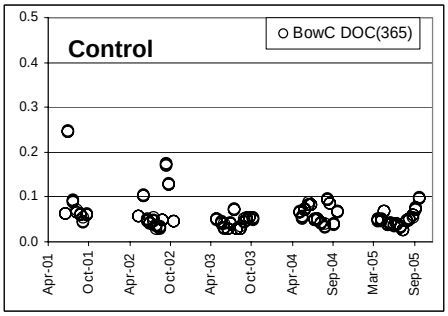
DOM in Bowron Streams

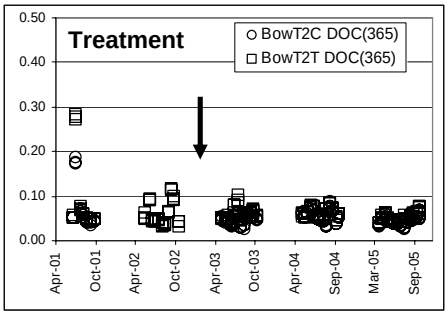
UVR (365 nm) absorption (cm^{-1}) by DOM measured

Naturally low UVR absorbencies

0.1 cm^{-1} = 32% UVR transmittance at 5 cm depth

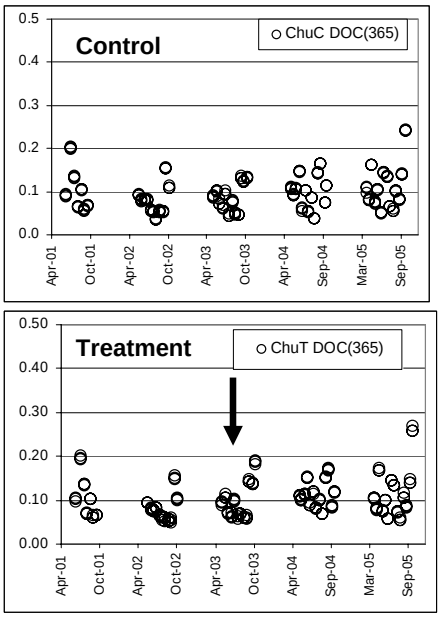
No significant change in DOM levels and UVR absorption in treatment stream after harvesting





DOM in Chuchinka Streams

- **UVR (365 nm) absorption (cm^{-1}) by DOM measured**
- **Naturally low UVR absorbencies**
- **No significant change in DOM levels and UVR absorption in treatment stream after harvesting**

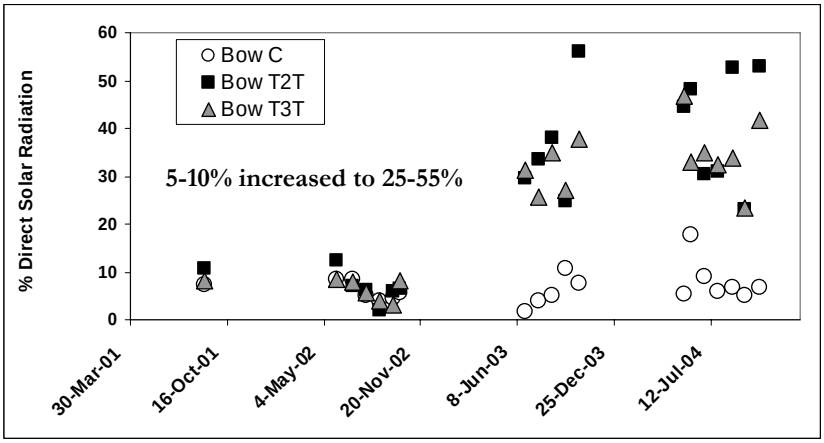


Direct Solar Radiation Exposure of Stream

- **Measure DOM UVR absorbance plus direct solar radiation exposure of stream**
- **Solar Pathfinder (stream level)**
- **Direct Solar Radiation exposure depends on stream aspect and canopy**

Low UVR absorbance by DOM + Reduced riparian shade

= UVR exposure of stream biota



% of total daily direct-solar radiation reaching stream surface for Bowron control stream and 2 treatment streams (Solar Pathfinder)

P.G. District Managers S4 Policy Objective

- #1: **Maintain 50 to 70% of the natural shade** and light intensity reaching the stream surface.

  • **Shade = 100% -% direct solar radiation reaching stream surface**

  • **DM Policy: Shade reduced from 90-95% to 45-75%**

  •**Meets policy objective but exposure significantly increases from 5-10% to 25-55% of total daily UVR (2.5-11 fold increase)**

DOM and Ultraviolet Radiation (UVR)

- **No changes in naturally low levels of DOM after harvesting**
- **Increases in stream exposure to UVR due to reduced shade**

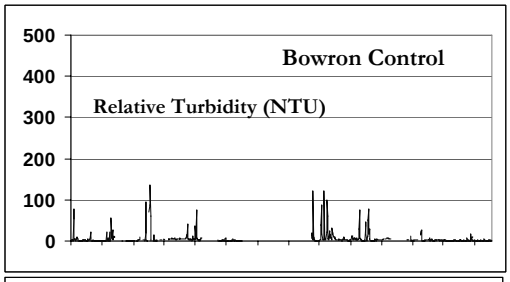
- **DM Policy enough?**
  - **UVR effects on biota still uncertain**
  - **Low DOM headwater streams may require higher shade retention for UVR protection of all biota**

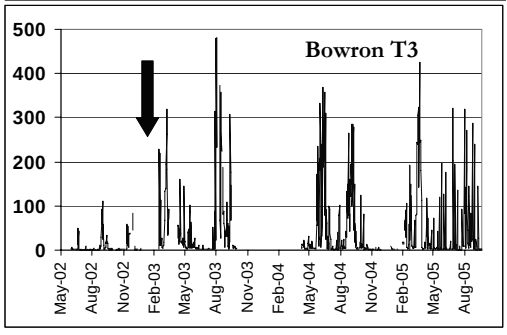
Water Quality and Suspended Sediments

• Sediments directly affect fish, and smother invertebrates, periphyton and spawning areas

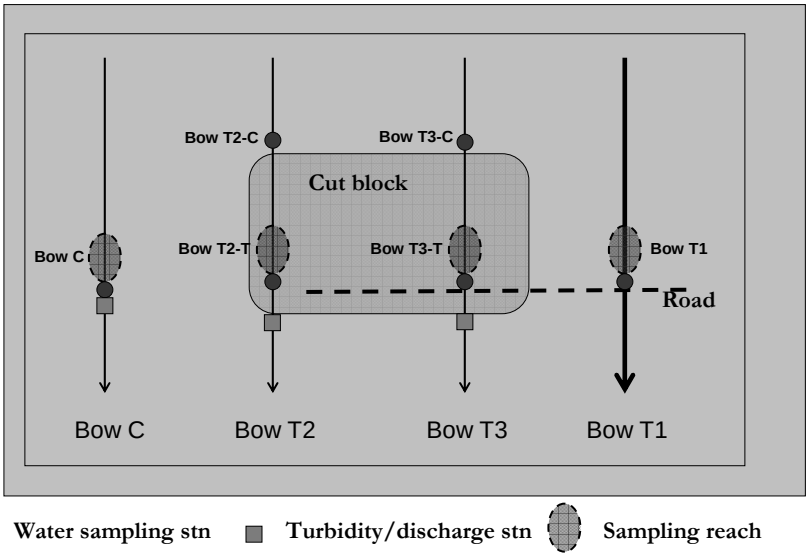
•Significant increases in suspended sediments after harvesting

• Largest suspended sediment impacts associated with road crossings, not riparian treatments





Site Schematic – Bowron Sampling Stns



Roads, roads, roads…..

Need to improve road crossing management on small streams to minimize sediment impacts

Fisheries Objectives for Sustainable Forestry Management of Headwater Streams

- **Maintain water quality (e.g. temperature, oxygen, suspended sediment, nutrients, water chemistry)**
  - **Retain shade, manage road crossings, manage organic debris loads, minimize watershed soil disturbances**

DM Policy prescriptions:

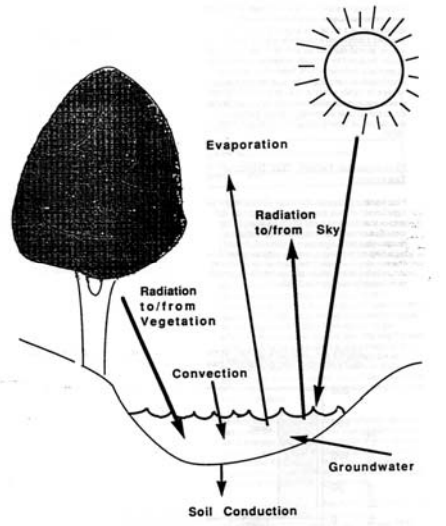
- **Nutrient and water chemistry unchanged**
- **DOM unchanged but UVR exposure of stream biota a concern due to reduced shade**
- **Significant suspended sediment impacts from road crossings**

Shade and Temperature

Outline

- Heat and temperature
- Stream type and temperature regimes
- Importance of temperature
- Small streams project
  - Shade
  - Air temperature
  - Water temperature
- Literature findings

Modes of Heat Transfer



- Solar Radiation
- Long-wave radiation
- Convection
- Evaporation
- Conduction
- Advection

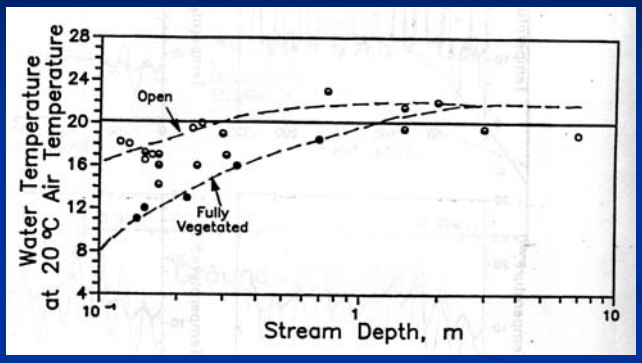
Environmental Factors

- Percent Shade
- Stream aspect and terrain
- Stream elevation
- Stream bank (e.g. undercuts)
- Streambed composition
- Stream depth and width

Environmental Factors (continued)

- Stream discharge
- Ambient air temperature
- Wind, precipitation, and day length
- Presence of hydraulic retention features
- Sources of stream water, type of geology, and water pathways.

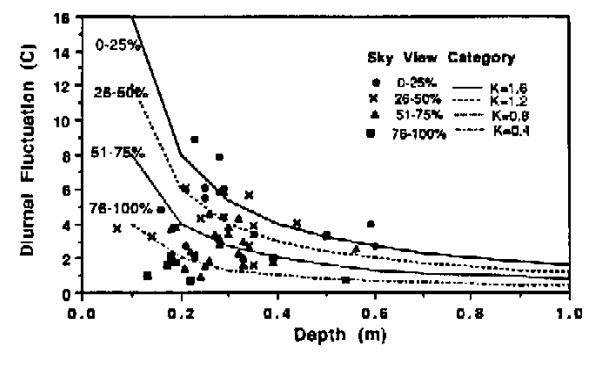
Influence of Stream Depth



From Adams and Sullivan 1990

Mean water temperature as a function of stream depth for fully vegetated and open sites.

Influence of Stream Depth and Shading



From Adams and Sullivan 1990

Diurnal fluctuation of water temperature in relation to stream depth at four different shading levels.

Interior vs. Coastal Streams

Interior streams

- Wetlands or lakes in headwaters.
- Moderate hill-slope gradients
- Cooler climate
- Lower storm frequencies
- Moderate annual precipitation
- Less cloud cover
- Dominant riparian canopy species (e.g., white spruce, lodgepole pine, subalpine fir).

Coastal streams

- Fewer wetlands or lakes.
- Steeper gradients and confined valleys
- Warmer climate
- High winter storm frequencies
- High annual precipitation
- More cloud cover
- Dominant riparian canopy species (e.g., red cedar, western hemlock.).

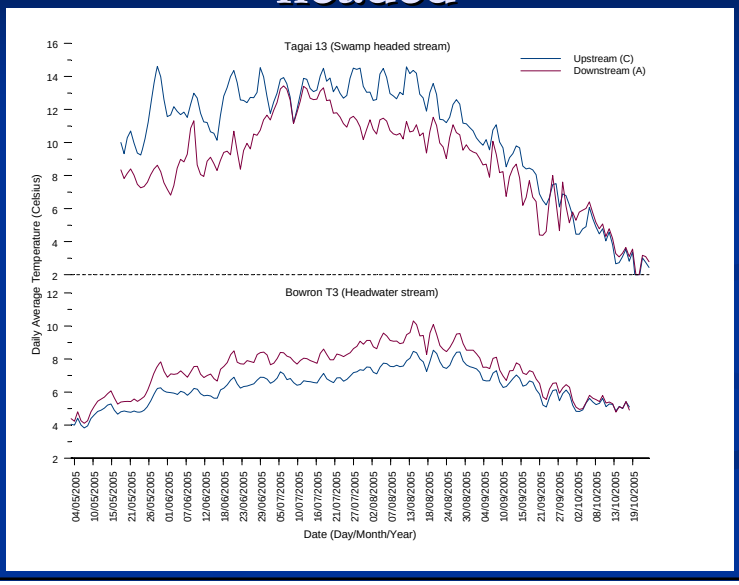
Shallow Headwater Streams

Questions for you

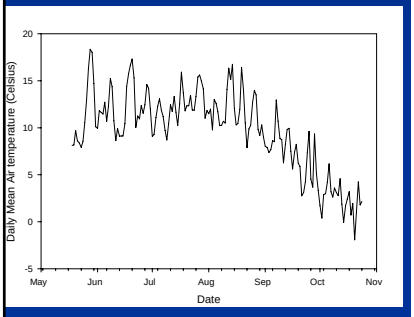
Are all small streams headwater streams?

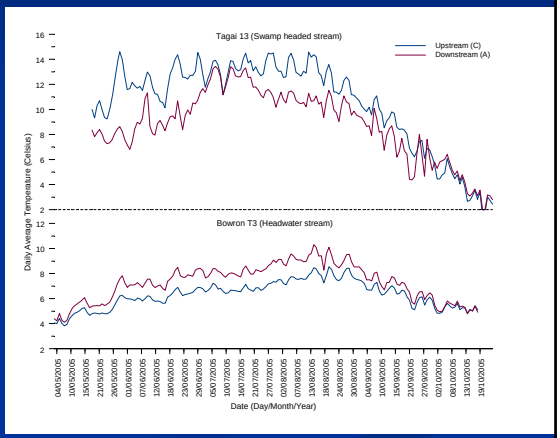
Does stream temperature increase or decrease in a downstream direction?

Headwater Vs. Lake/Wetland-headed



Seasonal Trends





Importance of Temperature

- All life stages of stream organisms;
- Algal and invertebrate productivity;
- Composition of aquatic organisms;
- Fish growth;
- Disease susceptibility;
- Development of salmonid eggs; and
- Survival and behaviour of fish populations.

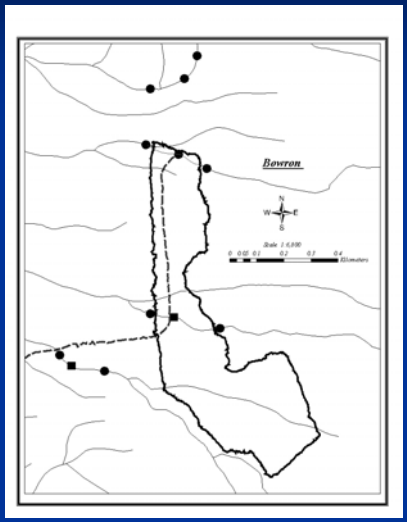
TABLE 4.8.—Lower lethal, upper lethal, and preferred temperatures (°C) for selected species of salmon, trout, and char based on techniques to determine incipient lethal temperatures (ILT) and critical thermal maxima (CTM).

Species	Lethal temperature (°C) Lower lethal[a]	Upper lethal[a]	Preferred temperature (°C)	Source	Technique
Chinook salmon	0.8	26.2	12–14	Brett (1952)	ILT
Coho salmon	1.7	26.0	12–14	Brett (1952)	ILT
		28.8[c]		Becker and Genoway (1979)	CTM
Sockeye salmon	3.1	25.8	12–14	Brett (1952)	ILT
Chum salmon	0.5	25.4	12–14	Brett (1952)	ILT
Steelhead	0.0	23.9	10–13	Bell (1986)	
Rainbow trout		29.4		Lee and Rinne (1980)	CTM
		25.0		Charlon et al. (1970)	ILT
Brown trout		29.9		Lee and Rinne (1980)	CTM
		26.7		Brett (1952)	ILT
Gila trout		29.6		Lee and Rinne (1980)	CTM
Apache trout		29.4		Lee and Rinne (1980)	CTM
Brook trout		29.8		Lee and Rinne (1980)	CTM
		25.8		Brett (1952)	ILT
			14–16	Graham (1949)	
Cutthroat trout	0.6	22.8		Bell (1986)	
Atlantic salmon		27.1		Brett (1952)	ILT
		27.8		Garside (1973)	ILT
Lake trout		25.0		Brett (1952)	ILT

[a] Acclimation temperature was 10°C; no mortality occurred in 5,500 min.
[b] Acclimation temperature was 20°C unless noted otherwise; 50% mortality occurred in 1,000 min.
[c] Acclimation temperature was 15°C.

Bjornn and Reiser, 1991

Small Streams Project



Shade

- One measurement every 5m for a 50m section of the treatment and control areas.
- Measured between 10am and 2pm.
- South facing and at the stream surface.

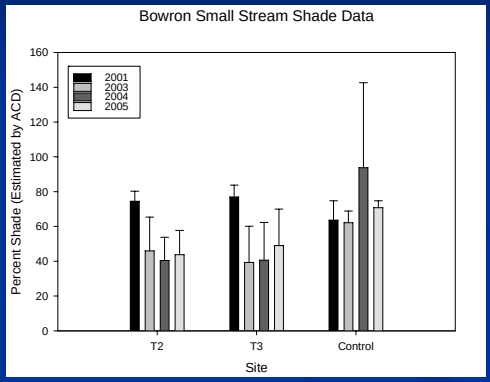
Pre-harvest Shading

- Angular canopy density in SBS ranged from 57 to 85%.

Leading Stand	Angular Canopy Density (%)
Aspen	65
Lodgepole pine	68
Spruce	71
Subalpine fir	82

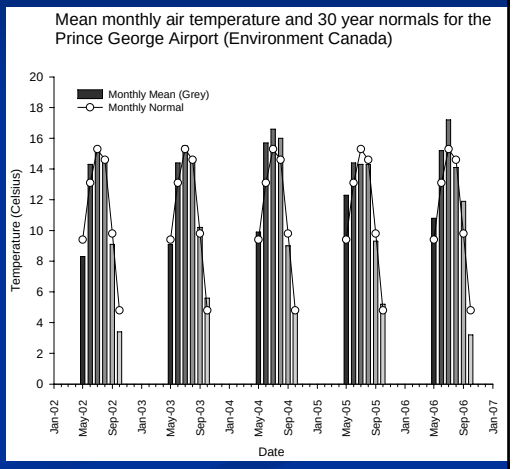
Shade Results

- Shade generally decreased after harvesting,
- Variability due to technique and natural variability,
- Shade levels at some sites are not statistically different from pre-harvest conditions 2-3 years after harvesting (i.e. a site specific response)



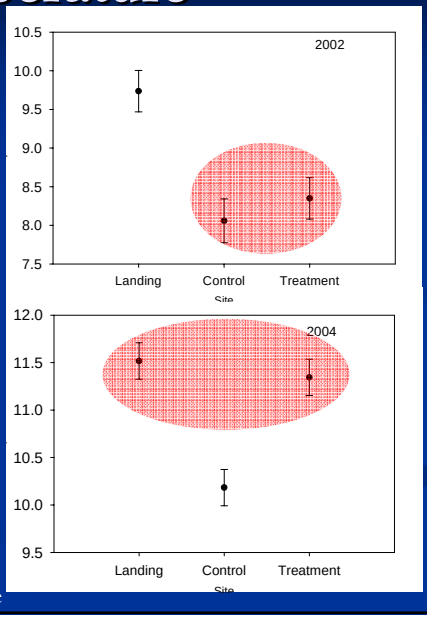
Climate Conditions

- Air temperature was not consistent.
- Unique opportunity to assess treatment effects over different conditions:
  - 2003 - normal
  - 2004 - monthly mean was 2^0C higher than normal
  - 2005 - warmer spring and cooler summer (~1^0C)
  - 2006 – May, June, July, and September (1-1.8^0C warmer), August was cooler



Air Temperature

- Pre-Harvest : Treatment sites were statistically similar to control areas.
- Post-Harvest: Treatment sites were statistically similar to landings (existing clearings).
- Greatest difference between treatment and control occurred in 2004, the warmest year regionally.



Y-Axis: LSM, X Axis: Site

Questions

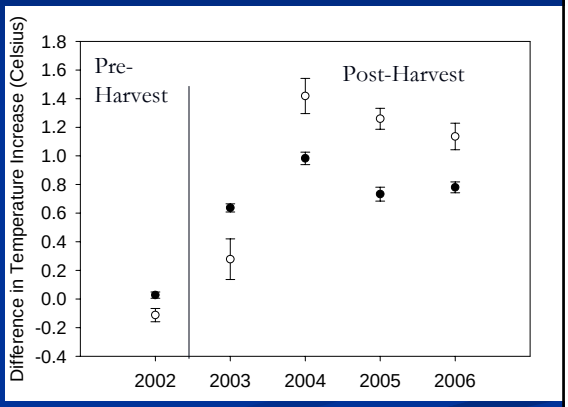
- Is an increase in air temperature important?
- How large a buffer would be required to prevent a change in air temperature?
- Given these results how much of a change do you expect to see in stream temperature?

Temperature Analyses

- Numerous techniques to analyze stream temperature, here we will look at three of them, namely:
  - Daily mean and maximum
  - Maximum mean weekly temperature
  - Diurnal fluctuation
- Some preliminary thermal recovery data are also presented.

Summary Water Results

- Statistically significant increase in water temperature following harvesting.
- Increase in daily mean was 1-1.5^{0}C higher than the control site.
- Is this an issue?



Bowron T2 Stream

It Depends

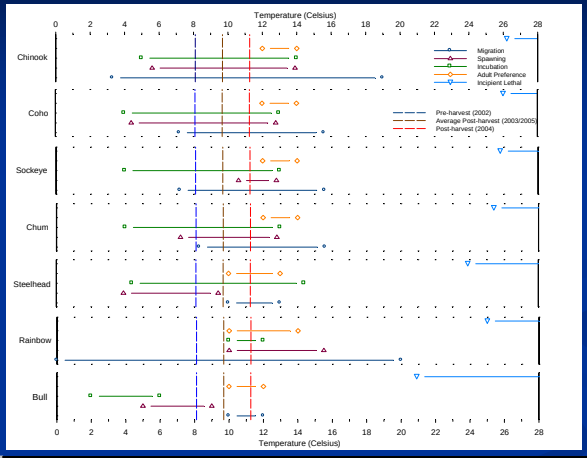
Chinook Salmon

Rainbow Trout

Sockeye Salmon

Bull Trout

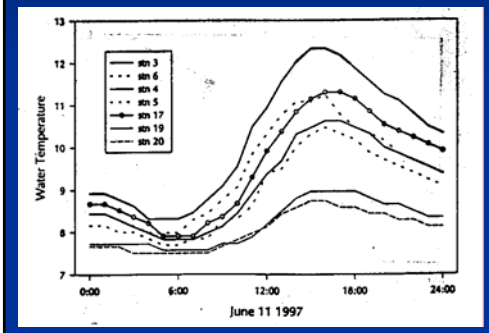
Fisheries Context



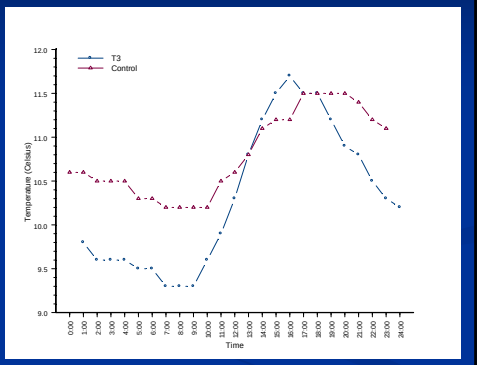
Bowron T3

	Bowron T3	Bowron T2	Bowron C	Chuchinka T	Chuchinka C
2002	8.1	10.0	9.6	12.0	10.9
2003	9.8	12.0	10.8	11.8	11.3
2004	11.3	14.3	12.2	13.9	13.5
2005	9.6	12.0	9.9	11.7	11.1

Diurnal Fluctuations

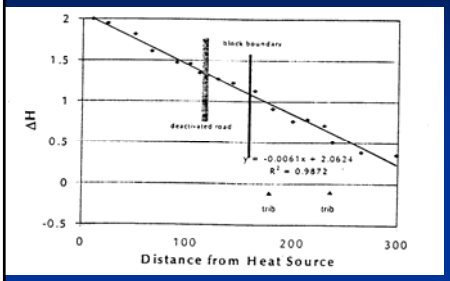


Torpy Study by Shrimpton, 1999

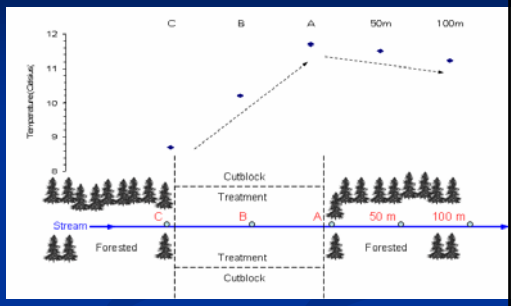


Bowron T3 site on August 14, 2005

Thermal Recovery



Torpy Study by Shrimpton, 1999



Bowron T3, stream hottest day and time in 2005,
C = 8.7 B = 10.2
A = 11.7 50m = 11.5
100m = 11.2

- Recovery is often due to dilution (groundwater or colder tributaries) and the rate may be enhanced by the degree of shading.

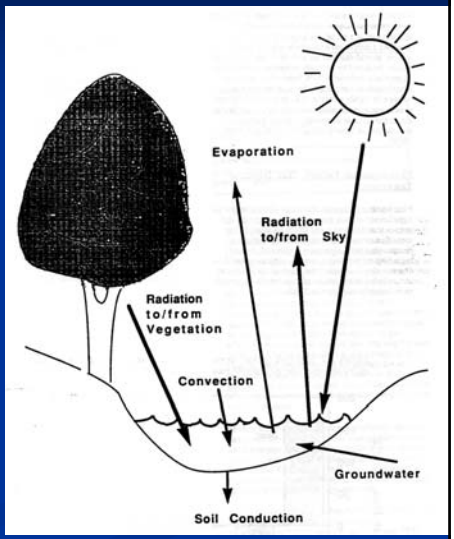
Literature Findings

Location	Treatment	Finding
W. Newfoundland[1]	0 and 20m	20m width appeared to keep stream's thermal regime and fish habitat
New Brunswick[2]	30 and 60m	Complex relationship between buffer width and stream warming
S. Ontario[3]	Variable	Buffers do not need to be wider than several meters, canopy height and species must be considered.
British Columbia[4]	Low-High Retention	Stream temperature changed, within limits of biota and did not recover within 5-7 years
W. Oregon[5,6]	8.6 - 30.5m	Buffers providing direct shade protected streams from increases above natural warming trend, ~1^{0}C
	0 – 20m	Temperatures increased earlier in the summer, up to 7^{0}C difference, recovery took 15 yrs

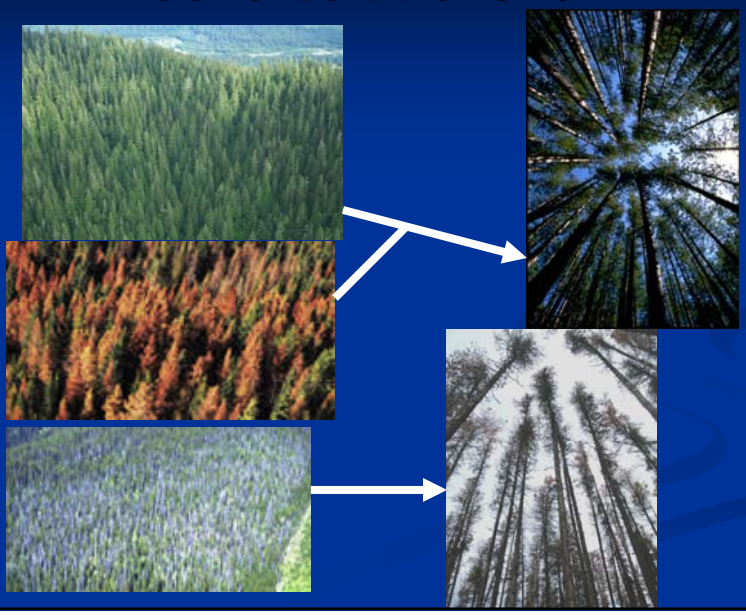
1. Curry *et al.* 2002, 2. Bourque and Pomeroy 2001, 3. Barton *et al.* 1985, 4. Herunter *et al.* 2004, 5. Zwieniecki and Newton 1999, 6. Johnson and Jones 2000

Conclusion

- The relationship is complex.
- Temperatures increased with the DM policy as did the diurnal variability.
- The policy may be effective for some areas but not all.



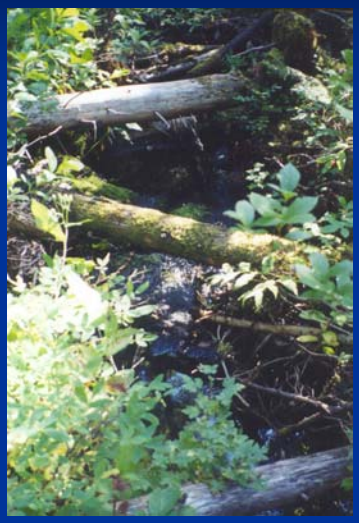
Considerations for MPB



Considerations

- As the riparian canopy opens energy exchange may be enhanced:
  - increasing local air temperature
  - and stream temperature.
- Increase riparian retention to:
  - decrease direct solar radiation,
  - prevent degradation of wetter areas.

Role of Large Woody Debris in Small Streams



LWD is woody material in the stream that is 5 cm in diameter and larger.

- increases structural diversity of stream;

Structural diversity includes formation of pools and drops, contributes to bank stability, and deflects stream flow and creates hydraulic diversity in the stream

Role of Large Woody Debris in Small Streams

- improves physical retention of organic matter and inorganic matter input from the surrounding forest;

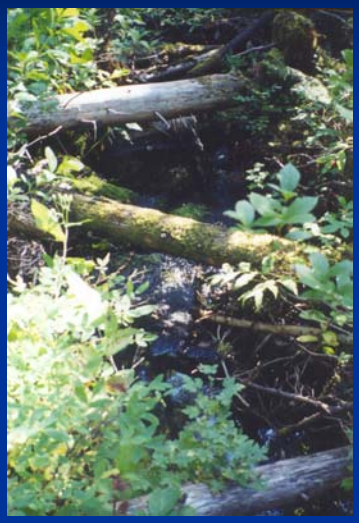
Role of Large Woody Debris in Small Streams

- direct food source for invertebrates (shredders and filterers;
- and detritus and algae can be directly eaten by aquatic consumers (small fish etc)

Role of Large Woody Debris in Small Streams

- refuge for fish and invertebrates,

Role of Large Woody Debris in Small Streams



- substrate for microbes and algae.
- This in turn influences nutrient cycling and downstream water quality

Interior vs Coastal Streams

Interior streams	Coastal streams
LWD recruitment from blowdown.	LWD recruitment from debris flows/ mass-wasting events and blowdown.
Woody debris jams not common	Woody debris jams common.
Riparian vegetation composed of different species	Riparian vegetation with red alder.
Smaller diameter trees.	Larger diameter trees.

Be careful of extrapolating Coastal studies to Interior situations

Important Characteristics of LWD in Small Streams

- Species,
- Diameter
- Density (number of pieces/length of stream)
- Orientation
- Embededness
- Period when functional (or zones of functionality)
- Span
- Decay Class

In general you are looking for a substantial variability in each of the characteristics, e.g.:

- You don't want all of the LWD oriented parallel to the streamflow
- You want variability in size, span and zone of functionality
- You want some pieces that are "bridging" the stream, while others that are fully submerged at all flows.
- In essence you need diversity and chaos, just like the terrestrial systems

DIVERSITY REIGNS IN UNDISTURBED SMALL STREAMS

Riparian retention prescriptions must ensure that diversity is maintained in the riparian area.

DM Policy Small Stream Project What we sampled

Streams:

- 80-160 cm wide
- < 6% slope

LWD:

- > 5cm diameter
- in and over the channel

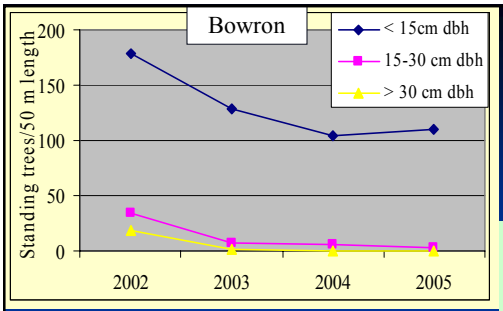
Stand:

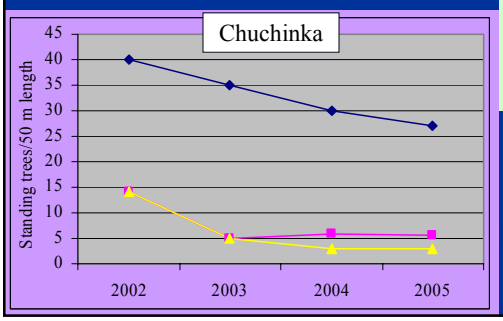
- 10 m wide

DM Policy Small Stream Project
What we sampled

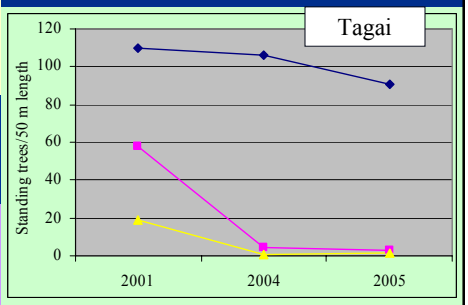
LWD Characteristics:

- Diameter
- Embededness
- Function at which flow
- Span
- Decay class
- Orientation
- Species
- Bole source distance
- Perpendicular source distance

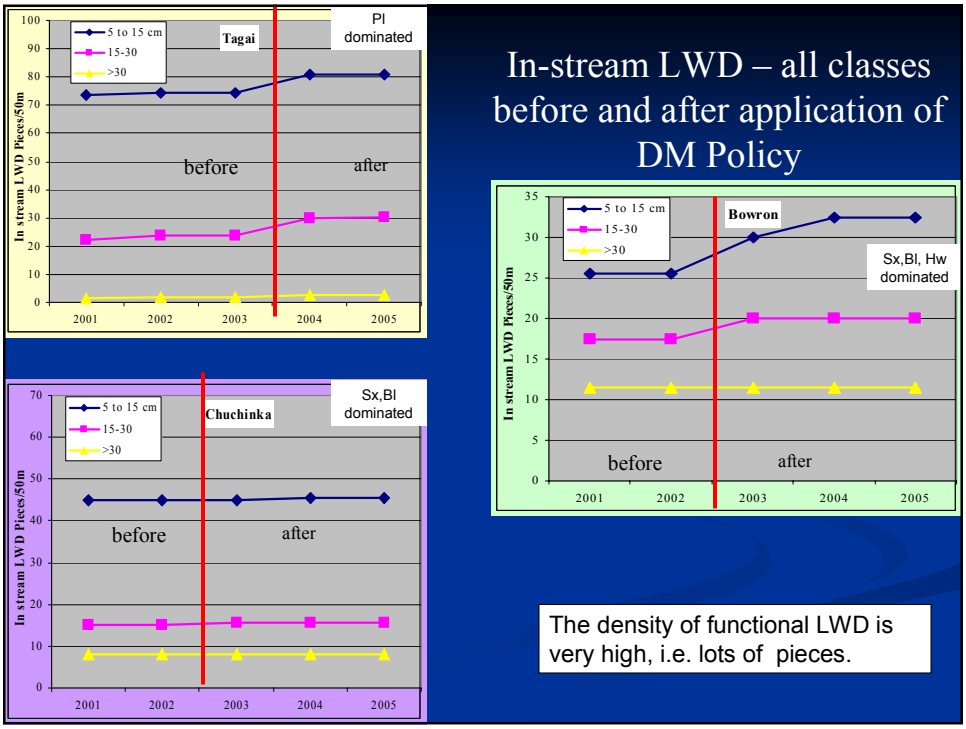




Number of standing stems in riparian zone (10 m on each side) before and after application of the DM Policy



Goal was to retain 10-12 stems >15cm diameter every 100m within 10-15m of the stream


In-stream LWD – all classes before and after application of DM Policy
Tagai
PI dominated
5 to 15 cm
15-30
>30
In stream LWD Pieces/50m
before
after
2001
2002
2003
2004
2005
Chuchinka
Sx,BI dominated
Bowron
Sx,BI, Hw dominated
The density of functional LWD is very high, i.e. lots of pieces.

WHAT DOES IT LOOK LIKE ON THE GROUND?

Bowron

- Average 16 stems standing / 100 m right after logging
- Average 6 stems/ 100 m in 2005
- Advance regeneration post treatment = 200 trees /100m

Chuchinka

- Average 20 stems standing/ 100 m right after logging
- Average 16 stems/ 100 m in 2005
- Advance regeneration post treatment = 60 trees /100m

Tagai

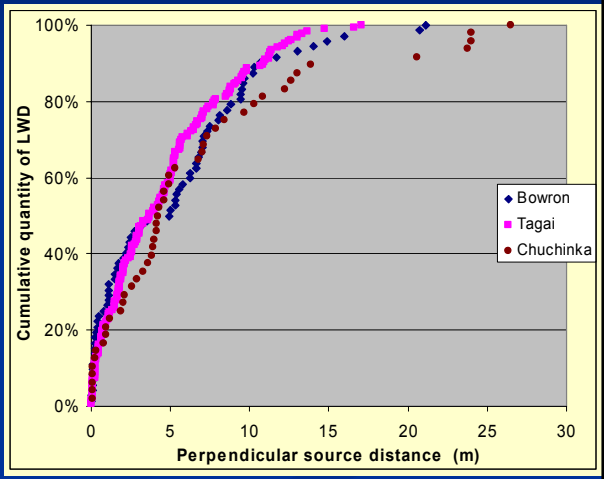
- Average 14 stems standing/ 100 m right after logging.
- Average 10 stems/ 100 m in 2005
- Advance regeneration post treatment = 200 trees /100m

Location of the LWD

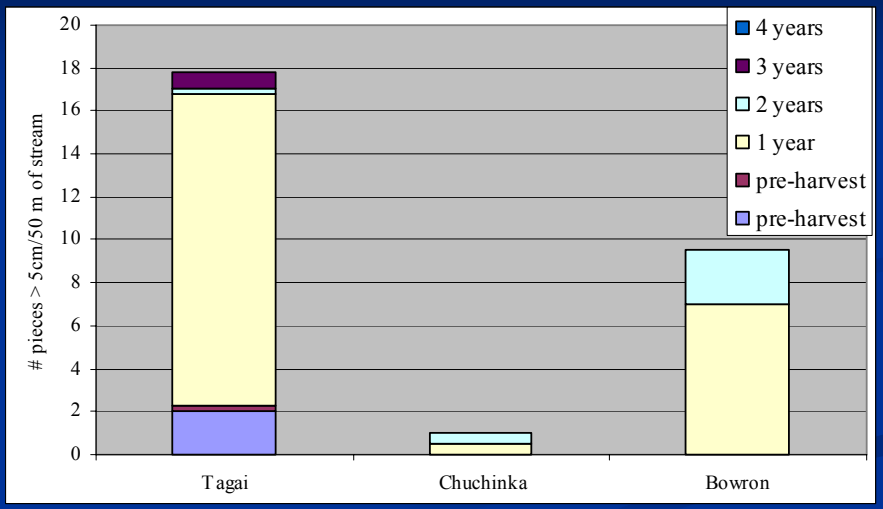
- Most small LWD enters the stream directly.
- Larger LWD is suspended over stream until broken.
- More decayed LWD found in stream.
- For the most part, LWD stays in place (i.e. not rafted downstream)

Source Distance

- Source of LWD within 10 m of stream.
  - Bowron 86%
  - Tagai 89%
  - Chuchinka 77%
- Related to stand height.
- Farther in spruce stands and wetter subzones.



Windthrow recruitment



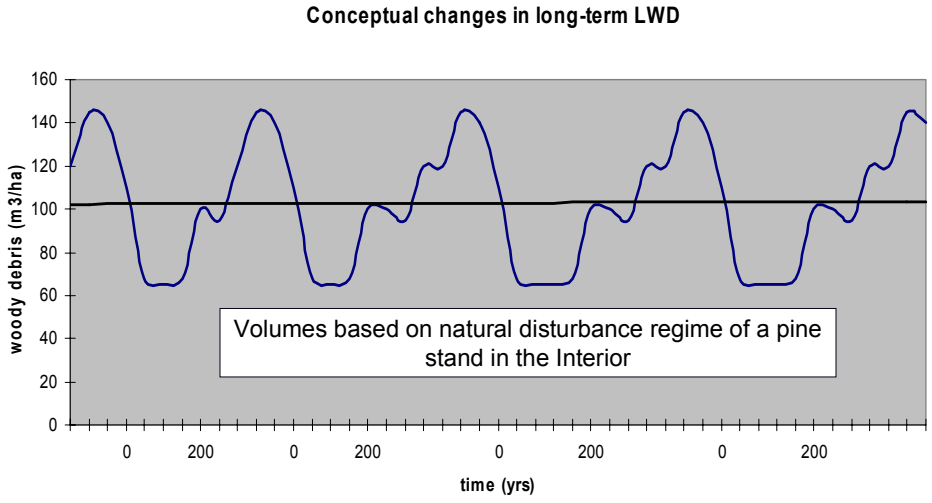
How do we know if it is enough

- We studied several LWD decay models (e.g. Murphy and Koski 1989), both in-stream and on land
- We wanted to model the amount of LWD in our streams at a future point in time
- None of the models were a perfect fit for our small headwater interior streams.
- However, we did use the information to build a reasonable conceptual model.

Rate of LWD Decomposition

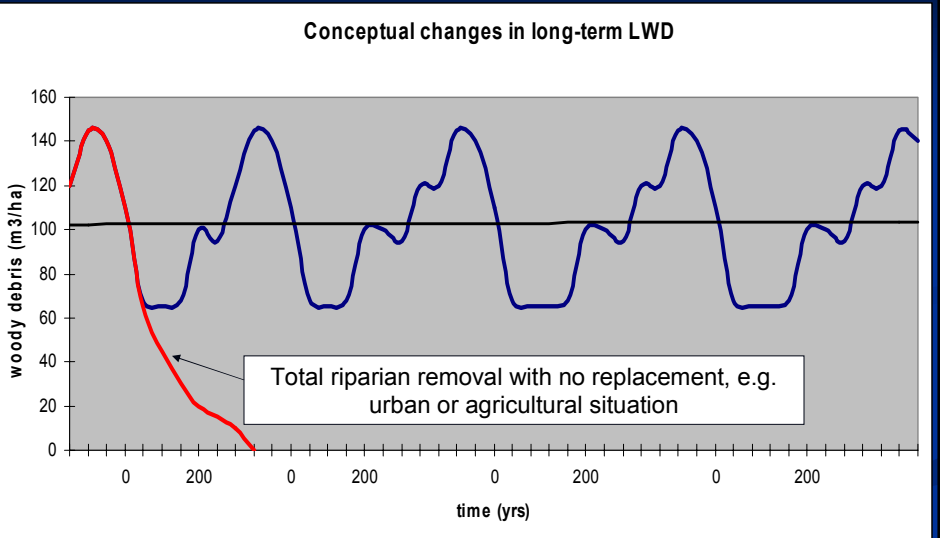
- Submerged wood decays slower than terrestrial wood or wood that is wetted and dried.
- Conifer decay rates are slower than deciduous decay rates.
- In one 5 year study loss of bark was the main contributor to diameter loss of LWD (Bilby et al. 1999).

Instream woody debris volumes



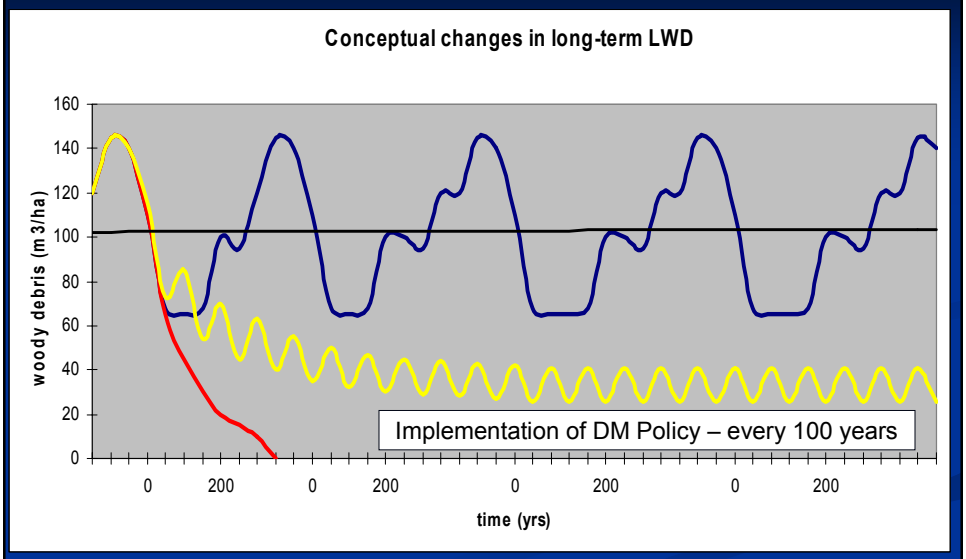
Clark et al. CJFR 1998 (28) 284-290

Instream woody debris volumes



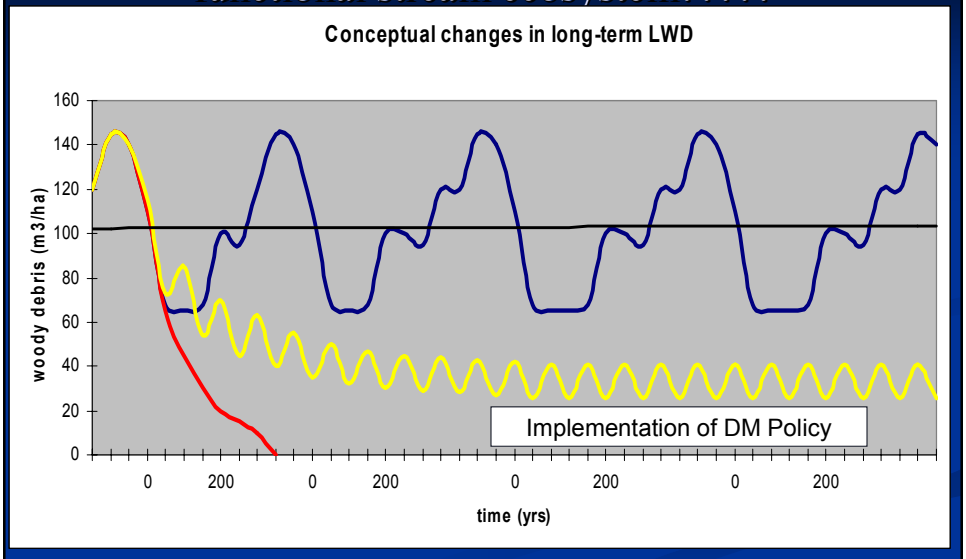
Clark et al. CJFR 1998 (28) 284-290

Instream woody debris volumes



Clark et al. CJFR 1998 (28) 284-290

Is the yellow line enough to maintain a functional stream ecosystem?????



Clark et al. CJFR 1998 (28) 284-290

LWD Model Conclusions

- The continued implementation of the DM policy will result in a substantial reduction in in-stream LWD (~ ~60%)
- Channel deterioration will likely occur over the long run.
- More retention is suggested as stream sensitivity increases

What are the possible long term implications of reduced LWD?

- Channel simplification
- Loss of immediate habitat
- Downstream impacts such change to sediment supply, change in invertebrate drift + ???????

The LWD modeling suggests that the minimum DM Policy will not provide enough LWD for long term sustainability. However, most operations leave much **more** than the minimum required by the policy.

Channel Morphology

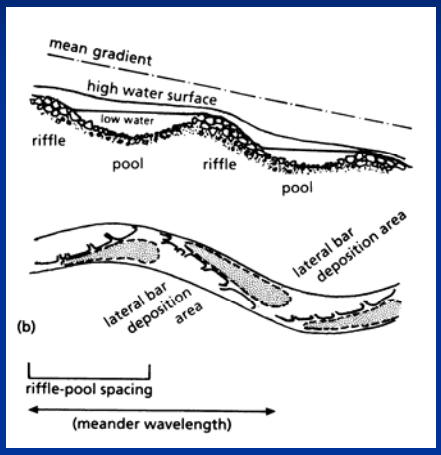


Diagram from Church 1992

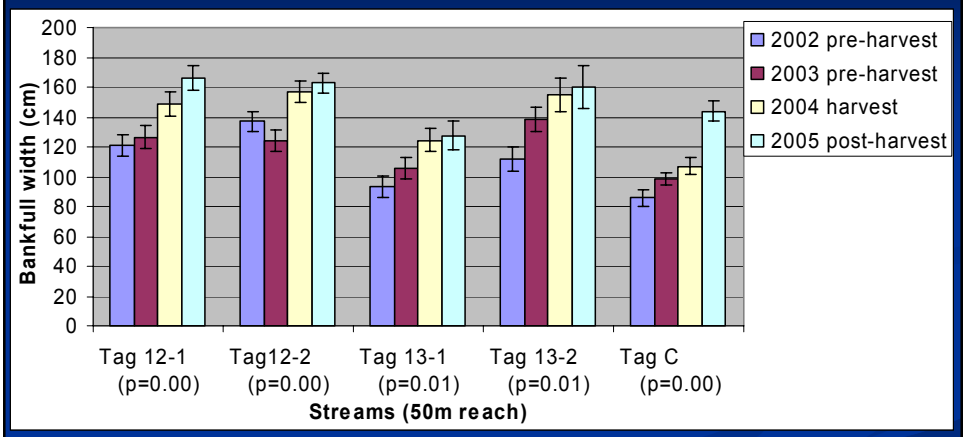
- Provides habitat complexity through variety of channel structures and stream velocities.
- Variety of habitats supports more diverse algal, invertebrate and fish assemblages and possibly more resilience to natural disturbances.
- Includes variability in depth, width, gradient, pattern, sinuosity, bed material etc

For the small stream project we chose to measure changes in average width and average depth and also their variability.

Possible outcomes from severe disturbance of the watershed and more specifically the riparian zone include:

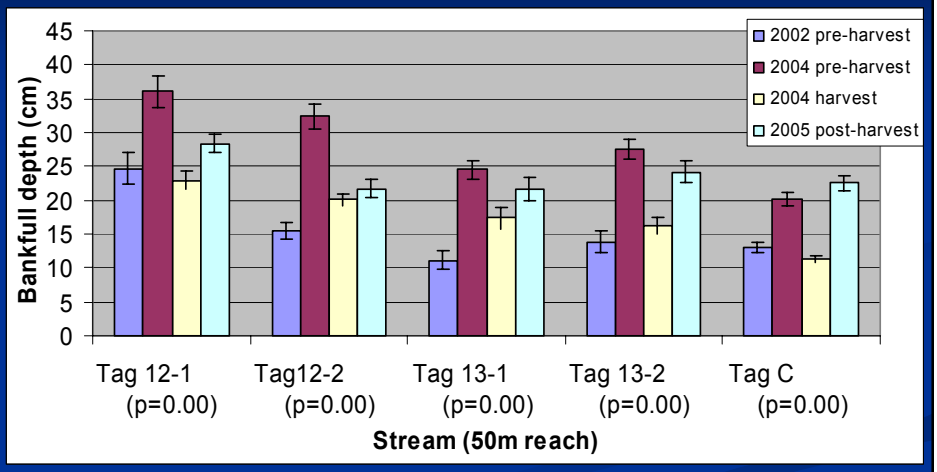
- Increase in average channel width
- Decrease in the variability of channel width
- Decrease in average channel depth
- Decrease in the variability of channel depth

Changes in Bankfull Width



Width increased over time at all sites, including control – no treatment effect detectable

Changes in Bankfull Depth



Width and depth measurements are very difficult to collect accurately and precisely. Defining where to take the measurement is very subjective and the measurement error is very large compared to the variable being measured.

Possible Implications for MPB Zone

- Small streams need LWD
- The beetle itself does not remove the LWD source
- The dead MPB trees may fall in the stream sooner but they are still a gradual source of LWD
- The DM Policy requirements (i.e. 10-12 trees >15 cm) should remain the absolute minimum target. The data suggests that a few more are required (even if all dead pine).
- If there is a species mix in the riparian, retain living mature trees first and make up the rest with the dead pine.

Prince George Small Stream Riparian Buffers Study

Riparian Management and the Productivity of Headwater Streams

Erland MacIsaac, Science Branch, Fisheries and Oceans Canada
School of Resource & Environmental Management, Simon Fraser University

Fisheries Objectives for Sustainable Forestry Management of Headwater Streams

- Maintain water quality (e.g. temperature, oxygen, suspended sediment, nutrients, water chemistry)
  - Retain shade, manage road crossings, manage organic debris loads, minimize watershed soil disturbances
- Maintain physical habitat (e.g. pools, cover, undercuts, spawning gravels)
  - Retain large woody debris inputs and streambank trees, minimize new sediment sources
- Maintain stream productivity (e.g. litterfall, invertebrates, periphyton, fish)
  - Management currently hampered by inadequate knowledge

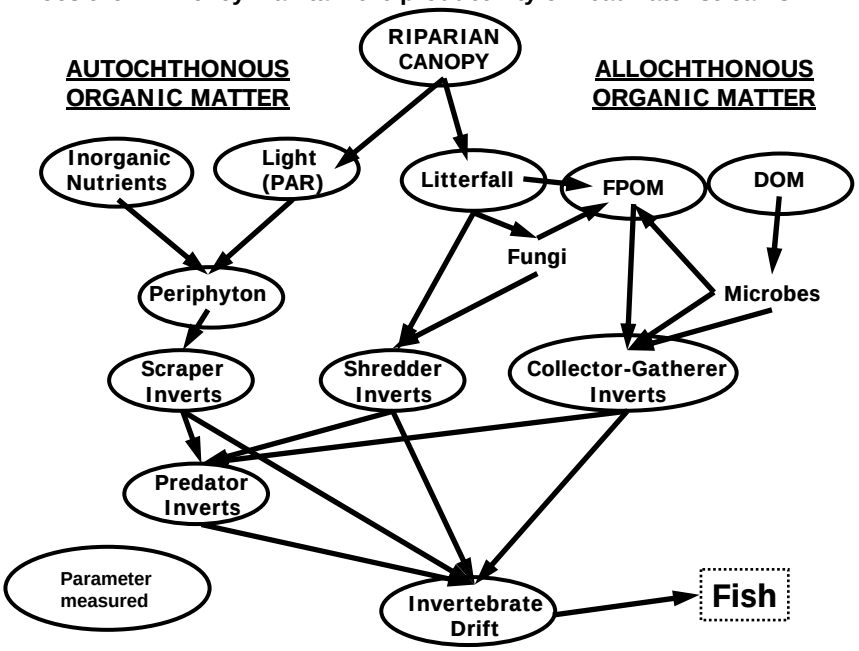
Expectations for Effects of DM Policy Riparian Prescriptions on Headwater Stream Productivity

- Some riparian trees harvested, shade declines, light increases *
- Inorganic nutrients (N & P) increase (watershed soil/vegetation disturbance) **
- Periphyton growth increases (more light & nutrients)
- Litterfall from overstory trees declines
- Increase in periphyton primary production compensates for litterfall decline
- Benthic invertebrates: "shredders" decline but "scrapers" increase

Stream productivity maintained or increased

*** Direct solar radiation increased 2.5-11 fold**
**** No change in nutrients detected**

Does the DM Policy maintain the productivity of headwater streams?



Key Headwater Stream Productivity Processes Studied

- **Organic matter inputs: leaf litter, periphyton (algae), DOM, fine particulate organic matter**
- **Stream canopy: light and shade (UVR and light for algae growth)**
- **Nitrogen and phosphorous nutrients**
- **Abundance of benthic macroinvertebrates**
- **Invertebrate drift (fish food)**
- **Downstream export to fish-bearing waters (nutrients, organic matter, invertebrate drift)**
- **Fish habitat use**

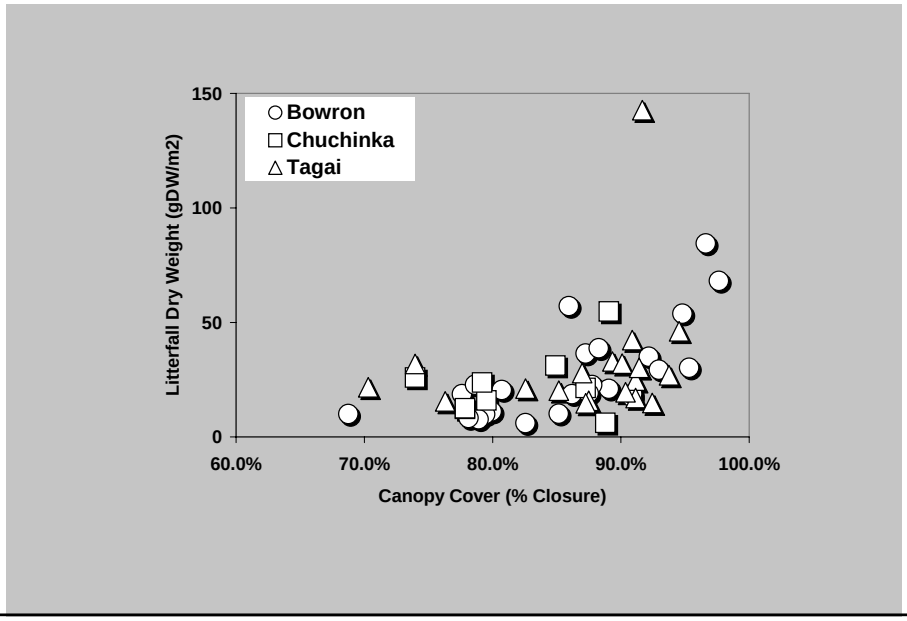
Do the DM Policy riparian treatments maintain stream productivity?

Litterfall Inputs

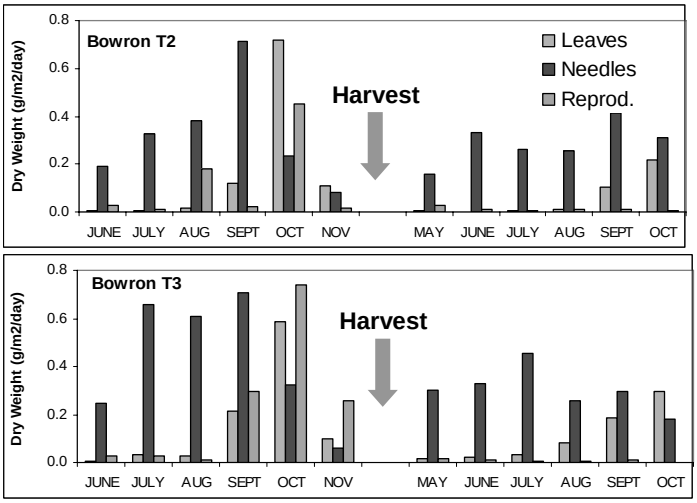
- **"Organic matter inputs to headwater streams dominated by litterfall"**
- **"Litterfall declines after riparian harvesting"**
- **"Shift to deciduous understory litter"**

- **May to October bank-to-bank collectors**
- **Spherical canopy densiometer**
- **No comparable interior BC data**

Pre-harvest litterfall vs % canopy closure for all 3 sites



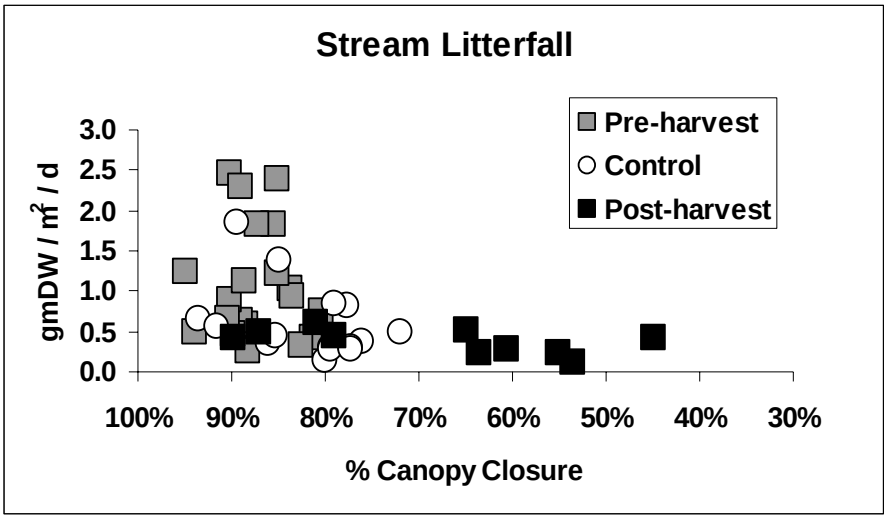
Changes in Litterfall Inputs to the Bowron Streams
Pre and post harvest years (2002/2003)



Leaf, needle and conifer reproductive part litter reduced after harvest

Litterfall vs % Canopy Closure – Bowron Streams

- **Litter not maintained by DM prescriptions (avg. 35% of natural)**
- **Canopy closure: poor indicator of impaired litterfall because natural variation high at high canopy closures**



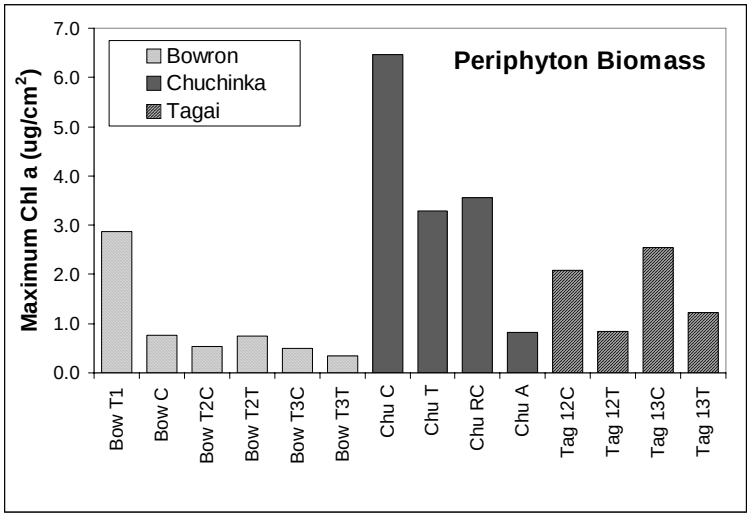
Shade and Light

- **Direct solar radiation exposure of Bowron streams increased 2.5 – 11 times**
- **Reduced shade:**
  - **increases light for periphyton growth**
  - **increases UVR exposure of biota**
  - **increases stream temperature**

Periphyton Production

- Periphyton (attached algae) require light, nutrients, stable substrates and moderate flows
- Periphyton methods
  - artificial substrates
  - 5 samplers per 50-m reach
  - chlorophyll accrual/max biomass
- Other parameters: direct solar radiation (solar pathfinder), canopy density, nutrients, temperature, discharge

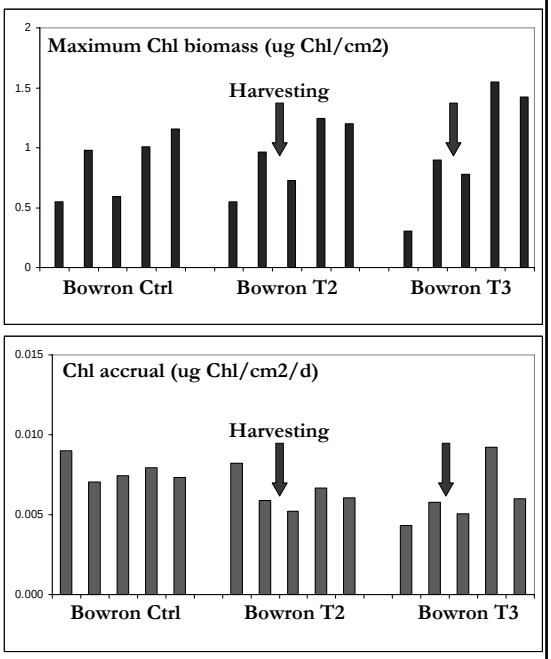
Pre-harvest geographic differences in maximum periphyton biomass (ugChl/cm2)



Levels indicate unproductive streams

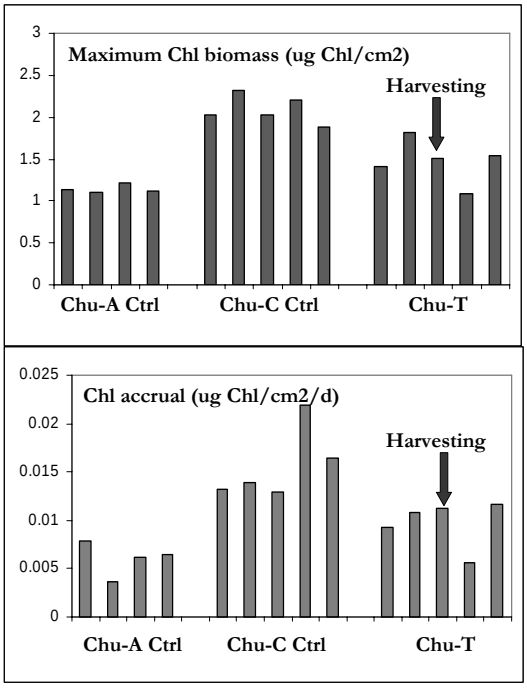
Periphyton Response to DM Policy Prescriptions

- **Bowron Streams**
- **No significant long-term change in maximum biomass after harvest (low)**
- **No significant long-term change in periphyton accrual rates after harvest (low)**
- **Post-harvest growth suppression?**
- **Periphyton production remains low despite light increases**



Periphyton Response to DM Policy Prescriptions

- **Chuchinka Streams**
- **No significant long-term change in maximum biomass after harvest (low)**
- **No significant long-term change in periphyton accrual rates after harvest (low)**
- **Post-harvest growth suppression ?**
- **Periphyton production remains low despite light increases**



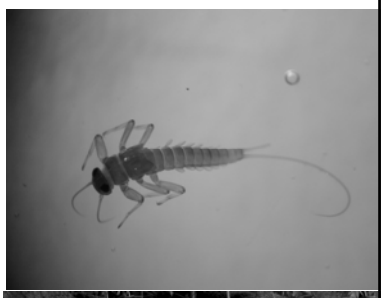
Periphyton Productivity

- Current views on algae in headwater streams
  - Periphyton growth limited by light (hi shade)
  - Riparian harvesting increases periphyton (reduced shade)
- Why no periphyton response to increased light due to DM policy?
  - Current views not supported
  - Nutrients (P) are very low: likely limit production in these headwater streams

DM Policy prescription has no large effect on periphyton production in these streams because of nutrient limitation

Macroinvertebrates

- Link between stream productivity and fish growth and survival
- High spatial/seasonal variability with complex life cycles
- Small changes difficult to detect



- Benthic invertebrates used as indicator of biological integrity
- Invertebrate drift provides fish forage
  - not all benthic invertebrates drift
  - drift high if stream productivity high
  - drift high if disturbed (short term)

Invertebrates - Methods

Surber Sampling

- **samples invertebrates living on/in the stream substrate**
- **sampled twice per year (spring/fall)**

Drift Sampling

- **invertebrates drifting downstream in the water**
- **sampled monthly, 24 hour collection**

Analysis

- **Total Abundance and Total Biomass**
- **Taxon Order (Ephemeroptera, Plecoptera, Tricoptera, Diptera)**
- **Functional feeding groups (e.g. shredders)**

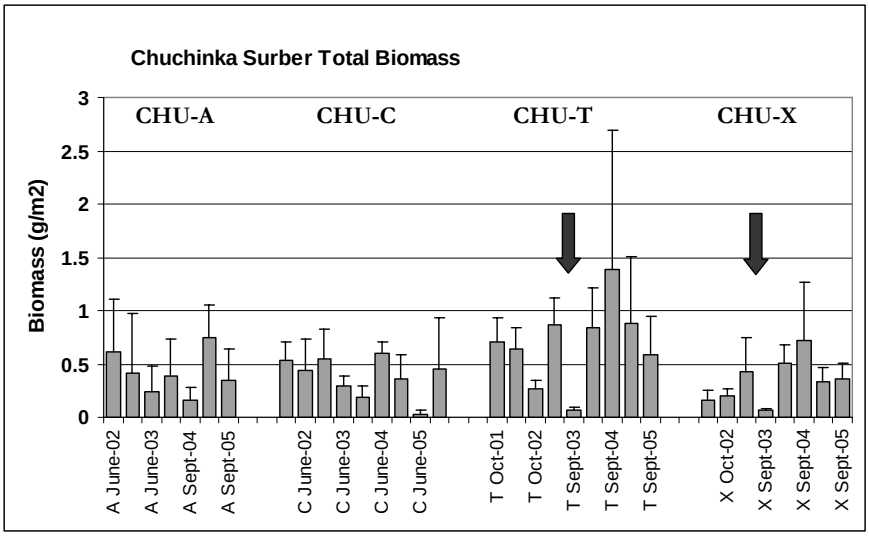
Invertebrate Total Abundance and Biomass

• many studies have found increased invertebrate abundance/biomass after forest harvesting

- **Increased light and nutrients**
- **Increased algae growth**
- **Increased organic matter**
- **Increased temperature**

Total Benthic Invertebrate Biomass

Subtle composition changes hidden



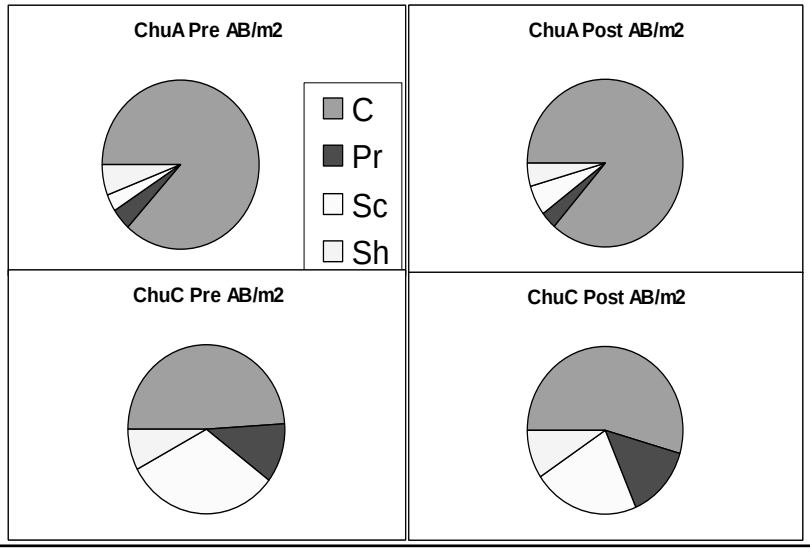
Invertebrate Functional Feeding Groups

Basic Food Types:		**Basic Feeding Groups:**
CPOM	**(litter)**	**Shredders**
FPOM	**(detritus)**	**Collectors**
Periphyton	**(attached algae)**	**Scrapers**
Prey	**(other invertebrates)**	**Predators**

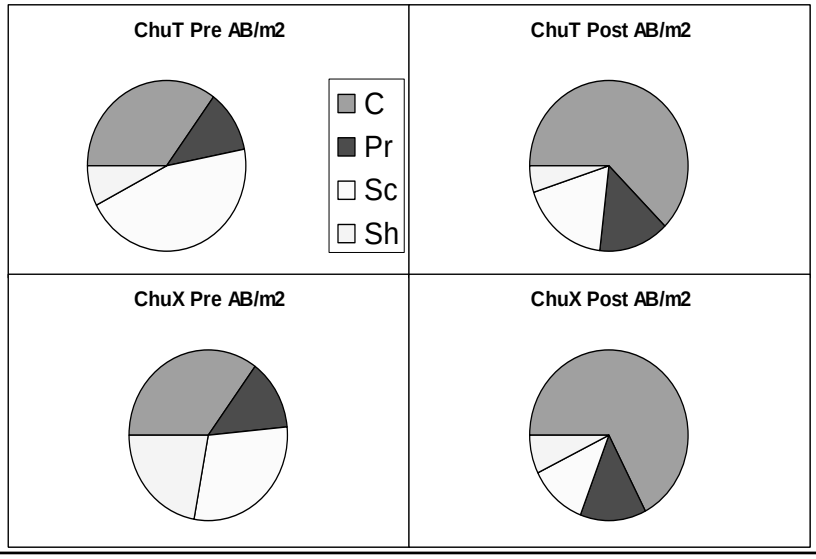
Changes in organic matter inputs can affect functional feeding group composition of invertebrate communities

E.g. Logging may reduce litter, increase periphyton, and increase detritus

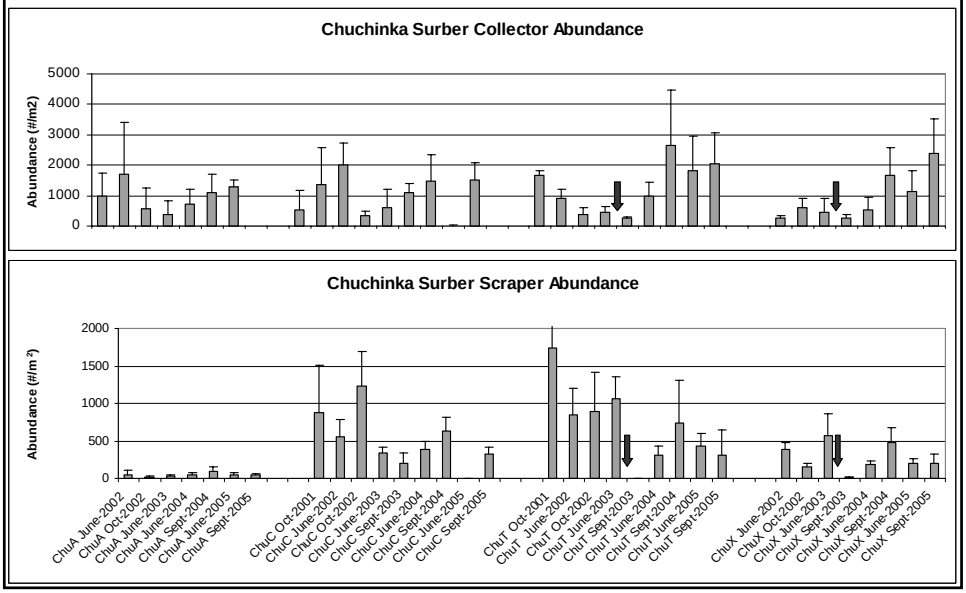
Chuchinka Control Streams
Pre Harvest/Post Harvest Feeding Group Composition
(collectors, predators, scrapers, shredders)



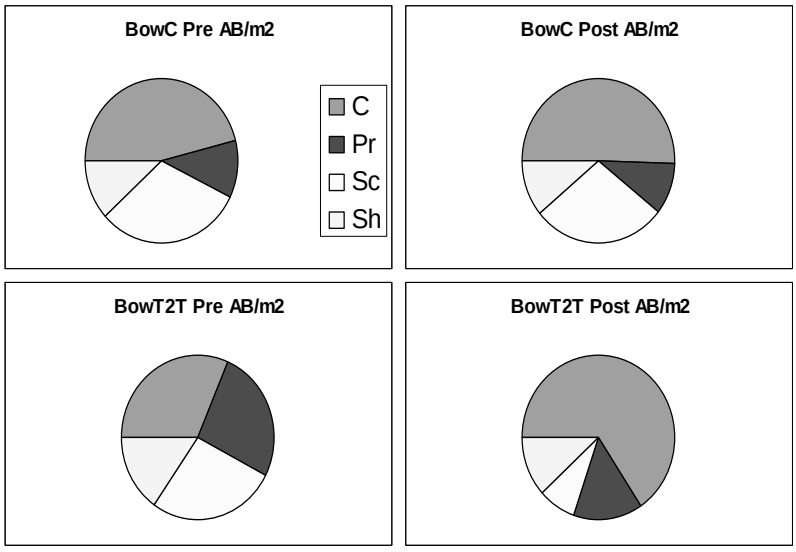
Chuchinka Treatment Streams
Pre Harvest/Post Harvest Feeding Group Composition
(collectors, predators, scrapers, shredders)



Detritus collector-gathers replacing algal/biofilm scrapers

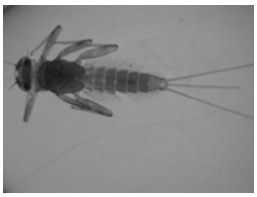


Bowron Control and Treatment Streams
Pre Harvest/Post Harvest Feeding Group Composition
(collectors, predators, scrapers, shredders)



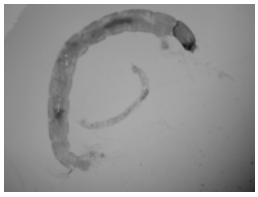
Taxon changes may reflect changes in stream productivity and organic matter sources

Mayfly scrapers



Periphyton/biofilms

Chironomid Collector-Gatherers



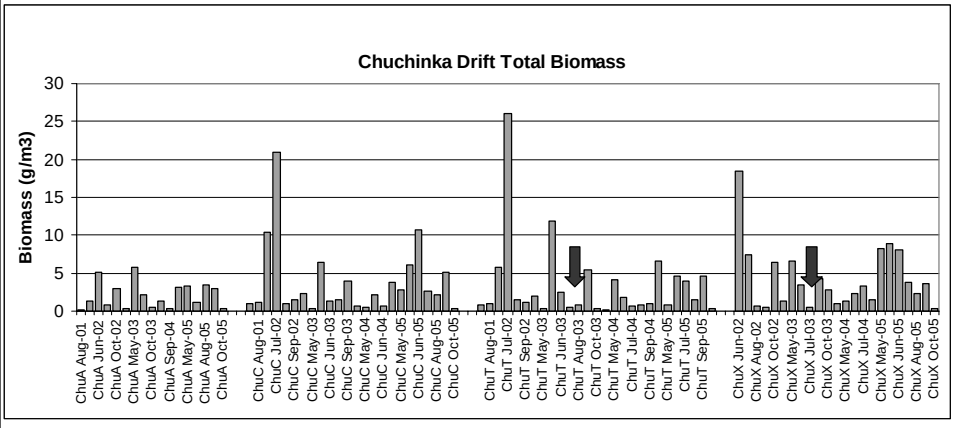
Fine organic detritus

Implications for invertebrate drift production and fish forage

- **quality of drift (prey size)**
- **seasonal patterns (life cycles)**
- **not all benthic invertebrates drift**

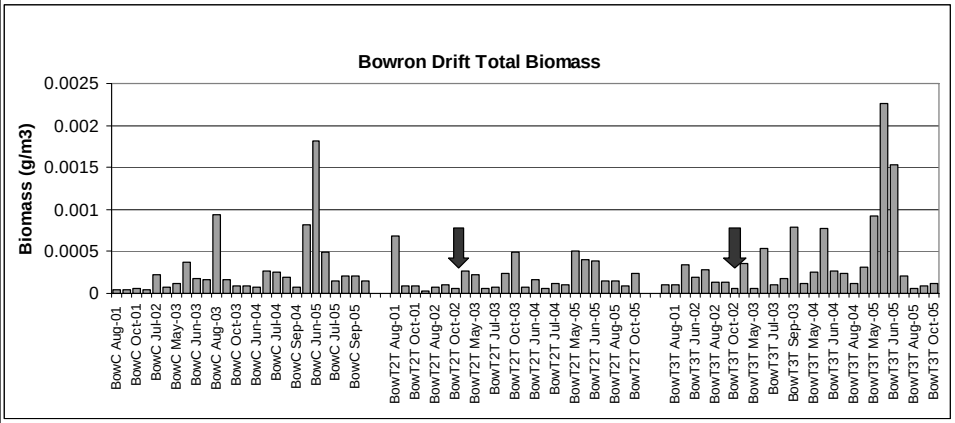
Drift Biomass - Chuchinka

- **no consistent changes in drift biomass after harvest**
- **drift highly variable (seasonal, taxa differences, disturbance responses)**



Drift Biomass - Bowron

- **no consistent changes in drift biomass after harvest**
- **drift highly variable (seasonal, taxa differences, disturbance responses)**



Invertebrates

- **Shifts in community composition indicate disturbance**
- **DM Policy changes organic matter sources, temperature, shade and UVR**
- **Implications of invertebrate changes to stream and fish productivity uncertain**
- **High variability coupled with very low productivity of headwater streams make detection of effects difficult**
- **Still analyzing data**

Fish

- **In small headwater streams, temporal and spatial variability of fish >> invertebrates**

- **Ephemeral use of streams**
- **Low densities**
- **Potential carrying capacity of stream and downstream habitat better indicator**

- **Note: streams are study surrogates for other tributary and fish-bearing streams**

Fish - Methods

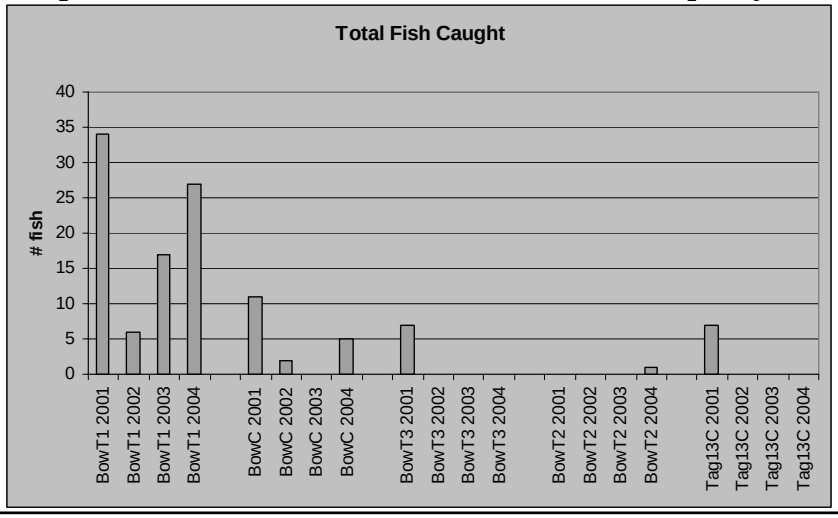
Fish traps CPUE, habitat use, condition, diet

Fish responses to forest harvesting can including:

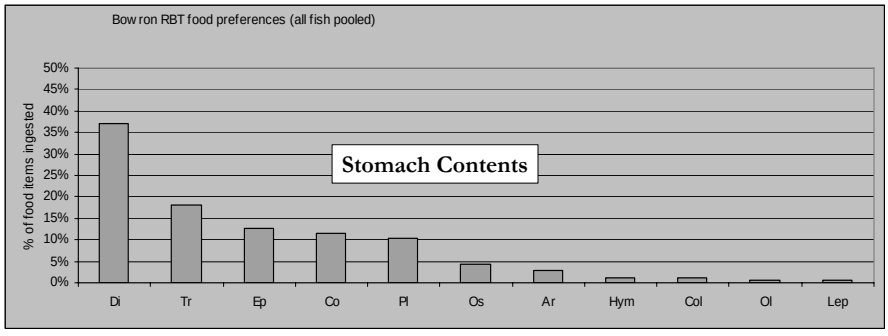
- growth rates (food, temperature)
- stress and survival
- spawning/egg incubation success,
- predation
- fish movement

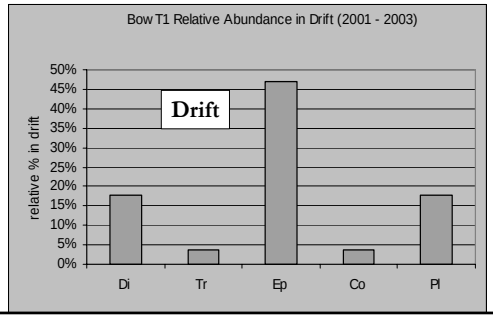
Fish – Bowron Stream Spatial Distribution

Ephemeral use by Rainbow trout – spring spawners
"Fish poor indicator of fish habitat"
Implications for stream fish inventories and DM policy



Fish – Drift vs Diet





Difficult to interpret invertebrate and drift changes because fish are selective feeders

DM Policy Prescriptions: Effects on Headwater Stream Productivity

- Shade declines, light (UVR/PAR) increases **YES**
- Inorganic nutrients (N & P) increase **NO**
- Periphyton increases (light, nutrients) **NO**
- Litterfall declines **YES**
- Primary production compensates for litterfall **NO**
- Stream productivity increases **NO**
- Invertebrates: composition changes indicate disturbance but effects on drift and fish forage difficult to interpret
- Note: productivity of these sub-boreal headwater streams is naturally very low

Riparian Function and Management of Small Streams 2005 Update

The Prince George Small Stream Project, whose members are comprised of Ministry of Forests Regional Research, P. Beaudry and Associates Ltd.; Department of Fisheries and Oceans, Science Branch and Canadian Forest Products Ltd., are working on describing and quantifying natural stream functions in small streams in the Prince George Forest District and the effects of forest management on these functions. Small streams are important because they make up a major portion (70-80%) of every watershed[1]. The project was initiated in the 2001 field season to determine if harvesting to the minimums specified in the Prince George District Manager's Policy for "Maintaining the Biological and Physical Attributes of S4, Small Fish-bearing Streams" ("D.M. Policy") maintains the necessary ecological attributes for healthy fish habitat. You may be familiar with this project having attended one of the field tours or the Natural Function of Small Streams course. This update provides some interim results for consideration when managing small streams in the SBS biogeoclimatic zone.

The experimental design for the project is based on a *Before-after-control-impact paired design (BACI-P)* described by Schwarz (1998[2]). This type of design has at least two types of sampling (before and after impact) in areas (treatment and a control) with biological and environmental variables being measured in combinations of time and space. In 2001 plots were established in 3 locations for intensive aquatic and riparian ecosystem monitoring:

1) Bowron - SBSvk, spruce-subalpine fir stand
2) Chuchinka - SBSwk1, white spruce-subalpine fir stand and
3) Tagai - SBSdw2, lodgepole pine stand.

The streams in this study are small (80 to 160cm bankfull width) and low gradient (3-6%). The sites were monitored for 2 years pre-harvest and monitoring has continued post-harvest. The sites were harvested to the minimum standards specified in the "D.M. Policy". The Bowron site was harvested in winter 2002/03, the Chuchinka in summer 2003 and the Tagai sites in spring and summer 2004.

The pre-harvest data have been compiled to describe natural stream functions in small streams in the SBS biogeoclimatic zone. A summary of some of the key findings documented to date are provided below:

There is a large range of woody debris found in these small streams. Every stream had an abundance of small woody debris pieces (5-15 cm diameter), and every stream had large woody debris, i.e. > 30 cm diameter. Small streams require a range of woody debris for channel and streambank stability and ecological diversity, for retention of organic matter, as a food source for invertebrates, a refuge for fish and a substrate for microbes and algae. On average, 60 to 80% of the woody debris was recruited from a distance of 10 m from the edge of the stream, while only 40-50% of the woody debris was recruited from within 5 m of the stream. Thus we suggest that trees retained for future woody debris contribution should be located within 10m of the stream. Source distance was related to stand height with taller stands having longer woody debris source distances. Blowdown of trees into small streams is a natural process.

[1] Gomi, T., R.C. Sidle, and J.S. Richardson, 2002. Understanding Processes and Downstream Linkages of Headwater Systems. BioScience, Vol. 52, No. 10.

[2] Schwarz C.J. 1998. Studies of Uncontrolled Events. *In:* Statistical Methods for Adaptive Management Studies. Res. Br, B.C. Min. For., Res. Br., Victoria, BC, Land Manage. Handb. No 42.

An average of 3 sediment sources (mostly old root wads) were identified for every 100m along undisturbed small streams. There were more natural sediment sources found on streams in lacustrine parent material.

These small streams are relatively cool in the summer months ranging from 6.7-10.6^{o}C with small daily fluctuations of 1 or 2 degrees Celsius. The low temperatures are attributed to stream shading and input of cooler groundwater along the length of these streams.

Rainbow trout were caught only intermittently in these small streams indicating that fish are a poor indicator of fish-bearing status in headwater streams. This is attributed to transient stream use dependent on annual stream flow conditions and variable recruitment of spawners from downstream populations.

Very low nutrient levels (nitrogen and phosphorous) and low levels of benthic invertebrates (i.e. insects that live on the bottom of the stream) were found in these streams when compared to data from coastal BC, suggesting that theses streams naturally have lower productivity than coastal streams of the same size.

Preliminary post harvest data have been collected at all treatment sites. We found that the D.M. Policy requirements for protection around small streams can be operationally achieved. The retention did not increase the number of sediment sources except on one site where there were very high levels of blowdown. Blowdown levels declined substantially the second year after harvesting. Not all blowdown contributed to woody debris in the stream. Some increase in turbidity (in-stream sediment) was noted, which was attributed to roads and skidtrails.

At two years post-harvest there have been no significant changes in stream width or depth, which is not surprising as there has been no time for wood or root decay and the streambanks were well protected with an effective 5 m machine free zone. The retained trees will contribute woody debris in the future and minimize changes to stream width and depth.

In the 2 years post-harvest the average, maximum and minimum stream temperature changed less than 3^{o}C, on average. The highest temperatures occurred in late July, early August corresponding to the warmer air temperatures at this time of year. This temperature change may have been larger in the absence of the retained buffer and riparian understory.

The low nutrient levels and low levels of benthic invertebrates have not changed during the first 2 years post-harvest despite the harvesting disturbances. There has been a reduction in downstream invertebrate drift. The post-harvest increased light levels, recorded at the stream surface, have not increased the abundance of periphyton, which is the matrix of algae and other microbes that grows on the stream bottom substrate. Their growth appears to be limited by the low stream nutrient levels. A reduction in the canopy biomass has resulted in a significant decrease in litterfall inputs; which are important for the productivity of these small streams.

The project researchers are continuing to monitor these sites to determine the changes that occur over time. To obtain more information on the Prince George Small Stream Project contact the researchers directly, attend the next Natural Function of Small Streams course (UNBC continuing studies), read published articles in Streamline (spring 2003), Trout Unlimited: Forest Land - Fish II Conference (2004), American Water Resources Assoc. Riparian Ecosystems and Buffers (conference 2004); or look for a new MOF website on fish-forestry projects (due on the Ministry of Forests website by December 2005).

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SECTION I
Policy for Maintaining the Biological and Physical Attributes of S4, Small Fish-bearing Streams

This policy sets out five objectives that should be recognized to address the biological and physical habitat requirements of small fish-bearing streams (S4). These objectives will guide the statutory decision maker in making a determination to approve an operational plan with respect to the management of S4 streams. By setting out these objectives and the companion guidelines document, it is anticipated that prescribing foresters and reviewing foresters will be able to prepare and review prescriptions and plans while knowing the statutory decision maker's expectations. This document presents the key elements that should be considered and evaluated in any prescription or plan.

PURPOSE:

The purpose of this policy is to communicate the guiding principles that the district manager will use to structure his thought processes when making a statutory decision with respect to Section 41(1) of the *Forest Practices Code of British Columbia Act*.

AUTHORITY REFERENCES:

- Section 41 (1) of the *Forest Practices Code of British Columbia Act*
- Sections 39 (4)(a)(ii), (4)(b), (5)(a), and (5)(b) of the Operational Planning Regulation
- Section 37 (1)(f) of the Operational Planning Regulation
- Sections 59 and 60 of the Operational Planning Regulation
- *Fisheries Act*, Canada
- *Riparian Management Area Guidebook*
- *Fish-stream Identification Guidebook*, Second Edition
- Pierre Beaudry's report, *Riparian Management of S4 Streams in the Prince George Forest District* (April 1999)

PRINCIPLES:

Issue Definition:

These objectives are meant to describe the biological and physical habitat requirements of small fish-streams, and are based as much as possible on current scientific literature. It is expected that individual prescriptions will include site specific strategies designed to achieve these objectives and reflect local site and stand conditions.

Policy Decision:

Section 37 (1)(f) of the Operational Planning Regulation requires that a riparian assessment to determine the riparian class of streams must be available before a silviculture prescription may be approved.

Section 39 (4)(a)(ii) of the Operational Planning Regulation requires that for the area under a silviculture prescription and the area adjacent to that area, that the prescription contain a map that illustrates all streams and their riparian class.

Section 39 (4)(b) of the Operational Planning Regulation requires that for the area under a silviculture prescription and the area adjacent to that area, that the prescription describe and contain for each stream a reserve zone, where applicable, and a riparian management zone (RMZ), including a description of the residual basal area or stems per hectare to be retained within.

Section 39 (5) of the Operational Planning Regulation requires that the silviculture prescription addresses harvesting within riparian management areas (RMA). The prescription specifically has to address cross-stream yarding, debris management, stream bank protection, and maintaining shade for known temperature sensitive streams.

Guiding Principles for Management of S4 Streams:

Stream Classification:

A small stream classified as a fish-stream (S4) must be managed as a fish-bearing stream regardless of the method used to classify it. The licensee always has the option of classifying a stream in accordance with the *Fish-stream Identification Guidebook,* if they feel that default classification is in error. **Note:** Local area agreements, when developed, may also affect the classification of these streams.

It is inappropriate to classify a stream as S4, simply to avoid the process of stream classification, and then to manage the stream as though it were non-fish-bearing. The practice of "defaulting" all small streams to S4 results in an unnecessary expenditure when providing for fish passage at creek crossings and may necessitate different riparian management practices.

A reach should be assessed for fish presence, and a classification made as to whether it is a S4 or S6 stream. The results of such an inventory can be applied immediately to a silviculture prescription or a road permit design. It is not necessary to have the inventory approved by a government agency prior to its' use, but the inventory may be subject to a review to ensure that it was undertaken in accordance with the *Fish-stream Identification Guidebook.*

Riparian Management Objectives for S4 Stream RMZs:

Objective #1:

Maintain 50 to 75 percent of the **natural** levels of shading and light intensity reaching the stream surface and forest floor.

- Shading as assessed using the concept of angular canopy density (Pierre Beaudry's report, *Riparian Management of S4 Streams in the Prince George Forest District* (April 1999)).

Objective #2:

Maintain an adequate long and short-term supply of large woody debris (LWD) in the stream channel.

Definitions:

- Short-term: the 50 years immediately following forest harvesting.
- Long-term: the period between 50 and 150 years after forest harvesting. During this period a "new forest" will replace the harvested forest.

Detailed definitions of adequate and LWD are provided in Pierre Beaudry's report, *Riparian Management of S4 Streams in the Prince George Forest District* (April 1999).

Objective #3:

Maintain natural root structure adjacent to streams with particular emphasis on minimizing soil disturbance within 5 metres of the stream channel.

Objective #4:

Do not overload the stream with an excessive supply of fine organic debris (FOD).

Definitions:

- FOD: Branches and other fine logging slash.
- An excessive supply is an amount sufficient to alter or divert the stream flow.

Objective #5:

Concentrate retention (both patch and single tree) in the most critical portion of the RMZ, that is the 10 - 15 metres closest to the stream.

SECTION II

Guidelines to Assist Prescribing Foresters in Developing Management Strategies Which Will Achieve the Desired Management Objectives for S4 Streams

SCOPE:

This district manager's guideline provides recommendations to prescribing foresters on how they may achieve the management objectives described in the District Manager Policy for riparian management of S4 streams. It provides a body of information that will guide the statutory decision maker in making a determination to approve a silviculture prescription with respect to the management of the biological and physical habitat requirements of a small fish-stream (S4).

PURPOSE:

The purpose of this guideline is to communicate the district manager's expectations with respect to best practices that could be employed to manage S4 streams. The strategies outlined in this document will be considered by the statutory decision maker when making a determination to approve an operational plan under Section 41 (1) of the *Forest Practices Code of British Columbia Act*.

AUTHORITY REFERENCES:

- Section 41 (1) of the *Forest Practices Code of British Columbia Act*
- Sections 39 (4)(a)(ii), (4)(b), (5)(a), and (5)(b) of the Operational Planning Regulation
- Section 37 (1)(f) of the Operational Planning Regulation
- Sections 59 and 60 of the Operational Planning Regulation
- *Fisheries Act*, Canada
- *Riparian Management Area Guidebook*
- *Fish-stream Identification Guidebook*, Second Edition
- Pierre Beaudry's Report, *Riparian Management of S4 Streams in the Prince George Forest District* April 1999

PRINCIPLES:

Issue Definition:

This document describes examples of strategies that could be employed to achieve the objective of maintaining biological and physical habitat requirements of small fish-streams, and are based as much as possible on current scientific literature. It is expected that individual prescriptions will include site specific strategies that reflect local site and stand conditions.

Policy Decision:

Section 39 (4)(b) of the Operational Planning Regulation requires that for the area under a silviculture prescription and the area adjacent to that area, that the prescription describe and contain for each stream a reserve zone, where applicable, and a RMZ including a description of the residual basal area or stems per hectare to be retained within it.

Section 39 (5) of the Operational Planning Regulation requires that the silviculture prescription addresses harvesting within RMAs. The prescription specifically has to address cross-stream yarding, debris management, stream bank protection, and maintaining shade for known temperature sensitive streams.

Strategies for Management of S4 Streams:

Points to Consider when Developing Site Specific Strategies:

- The prescription must describe and contain for each S4 stream, a RMZ including a description of the residual basal area or stems per hectare to be retained within.

- Large deciduous trees can be utilized to supply short-term LWD.

- Retention for LWD recruitment should target stems greater than 15 centimetres diameter at breast height (dbh). These trees should be positioned such that they will have a good probability of eventually falling across the stream channel.

- Basal area retention or stems per hectare retention do not need to cover the entire RMA, but rather cover an area large enough to achieve the desired objectives.

- The shape and size of retention patches should not be dictated by the RMA width, but rather the need to create a patch that is as windfirm as possible considering the timber type, stand structure, and topography. These patches may fill the role of wildlife tree patches.

- The natural brushy margins and deciduous cover along many S4 streams may be sufficient to achieve the shading objective. Where insufficient, additional retention may be required to meet the 50 to 75 percent shading objective.

- The slope and aspect of the block and the relative location of the stream within the block may be sufficient to meet most of shading requirements for the stream.

Examples of Strategies Which May Be Employed to Meet Management Objectives for S4 Streams:

Note: The examples do not preclude a prescribing forester from proposing alternatives that achieve the desired result, which is to protect the integrity of the stream and stream habitat.

These strategies take into account the stand structure of the forest through which the stream flows.

Examples of Strategies That Could Be Employed to Meet the Riparian Management Objectives for S4 Streams in the Prince George Forest District

STAND STRUCTURE	EXAMPLE PRESCRIPTION TO MEET MANAGEMENT OBJECTIVES
Single Storied	• The RMZ, within the cut-block, should be managed by leaving undisturbed windfirm residual tree patches (preferred option) and dispersed leave trees along the length of the stream. Riparian shrub or deciduous vegetation along many streams may provide adequate cover to achieve Objective #1. • When shade effective riparian vegetation is not present, patches should be retained which cover at least 40 percent of the channel and, where possible, be at least 150 metres in length. • Where shrubs or deciduous cover provides shading or the RMZ is being clearcut, LWD recruitment still needs to be accommodated by leaving 10 to 12 overstory trees per 100 metres of stream length to provide "short-term" LWD (evenly distributed). • The residual patches may also serve as wildlife tree patches. It is assumed that the residual patches will serve to meet the shade requirements. The residual patches will also provide the "long-term" supply of LWD.
Two-Storied (overstory and intermediate crown class only, no understory)	Release intermediate layer if of adequate stocking and quality. The intermediate layer and shrub layer will provide shade and control light intensities, while providing for the long-term supply of LWD. A minimum of 10 overstory trees per 100 metres of stream length should be retained to provide a supply of short-term LWD. These residual trees should be positioned such that they will have a good probability of eventually falling across the stream channel and should be greater than 15 centimetres dbh.
Multi-storied	25 to 35 percent of the basal area should be retained. If this objective can be met by leaving only trees in the intermediate class, then the removal of the overstory is acceptable. Advance growth in the understory should be protected, as it will be the source of the long-term supply of LWD. If the intermediate class does not provide 30 percent of the basal area, then 5 to 10 overstory trees per 100 metres of channel length should be left to provide for the short-term supply of LWD.

Natural Shelter-wood (overstory and advanced regeneration, no intermediates)	Remove the overstory, but leave 10 overstory trees per 100 metres of stream length harvested. Protect the advance regeneration during harvest. This will provide the long-term supply of LWD to the stream channel and the inputs of terrestrial detritus to the aquatic ecosystem, especially if the shrub layer is minimal.
Irregular (open overstory with abundant understory)	Release the intermediate and/or understory crown classes if either has adequate stocking and quality. Leave 8 to 10 overstory (C1) and intermediate (C2) trees per 100 metres of stream channel logged, evenly distributed along the length of the channel. Choose trees leaning towards the channel when possible. Advance regeneration must be protected.

T. P. (Phil) Zacharatos, R.P.F.
District Manager

A summary of results and implications for management of small streams in the Prince George TSA using the DM Policy for S4 streams (5-m machine free zone; retention of all non-merchantable stems and 10 merchantable stems per 100 m stream length) (Based on findings to Feb. 2006)

Stream or riparian characteristic	Associated Natural ecological functions	Variables measured in small stream project	Interactions with other stream processes	Expected time frame for changes to occur from riparian harvest[1]	Were there significant changest o individual sream characteristic?	Level of Concern for negative impacts to occur when using "DM Policy" (relative to individual characteristic).	Type of stream most sensitive to this change	Implications for small streams in MPB zone
Streamflow regimes	- controls rate of dowstream transport of sediment, LWD, organic matter - controls rates of channel migration and bank erosion - determines amount and quality of fish habitat (e.g. pool depth) - affects fish passage and movement	- continuous stream stage data - stage discharge curves	- sediment transport - channel morphology - invertebrate drift	Short term	Insufficient long-term data from co-op study; increased spring peakflows observed at Baptiste	**Not applicable**	Related to amount of watershed harvested, no so much riparian treatment	Increased flows caused by reduced ET (dead and salvaged trees) suggests more riparian retention to control bank stability and erosion
Fine sediment transport	- affects natural stream substrate condition (e.g. spawning gravels, invertebrate substrates) - maintains natural concentrations of suspended sediment in water	- continuous turbidity data	- sediment sources - invertebrate and periphyton abundance - suspended sediment effects on fish	Short-medium term	Yes (from roads and trails, not riparian treatment)	**LOW**	Related to quality of stream crossings	Because of very high road density, good erosion and sediment control at stream crossings is very important
Stream sediment supply	- maintains stream substrate condition (e.g. spawning gravels, invertebrate substrates, pool depths)	- identify stream sediment sources - streambank tree windthrow	- channel morphology - bank stability - nutrients	Short-medium term	No significant change, sediment supply maintained within natural range	**LOW**	lacustine parent material	Because of very high road density, good erosion and sediment control at stream crossings is very important
Channel morphology	- natural variability enhances diversity and influences biological productivity	- stream width and depth	- streamflow regimes - sediment transport and supply - large woody debris - bank stability	Long term	No significant change yet, however may be affected in the long term by reduced LWD supply	**MODERATE**	All except bedrock controlled channels	Riparian retention extra important as flows will increase.
Large woody debris	- stream structural diversity, channel morphology - retention of organic matter and sediments - fish cover and habitat - refuge for organisms - substrate for growth	- large woody debris in stream (quantity and age classes) - riparian recruitment distance - riparian composition	- sediment transport - streamflows - fish and stream productivity	Long term	No significant change yet, however modelling predicts a significant decrease in the future	**HIGH**	DM policy provides insufficient long term supply of LWD for all riparian types studied, with the worst impact being in ecosystems dominated by spruce and subalpine fir.	Retention of both dead and green riparian trees important (more than DM policy suggests)
Shade	- controls solar heating - minimizes UV radiation exposure of biota - controls photosynthetically active radiation for periphyton growth	- canopy density - angular densiometer - solar pathfinder (direct solar exposure)	- temperature - periphyton - invertebrates - cover for fish	Short term	Yes, a significant decrease	**HIGH**	"Temperature sensitive" streams; loss of cover for fish	Potentially reduced shade (fewer pine); more retention required.
Water Temperature Regimes	- cool water source (headwater streams) - affects all stream productivity processes - changes fish growth and health; egg survival - stream invertebrate community composition and productivity - invertebrate drift production	- water temperatures	- all stream biota and productivity processes	Short term	Yes, a significant increase, although relatively small	**MODERATE**	Designated temperature sensitive streams and those supporting temperature sensitive species such as Bull trout	More retention may be required in areas where shade is reduced from needle loss. Road crossings should be minimized to decrease stream exposure.
Litterfall	- dominant source of organic matter for headwate stream productivity	- litterfall traps - canopy density	- Invertebrates - Nutrients - Micro-organisms	Short term	Yes, a significant decrease	**HIGH**	All streams	Loss of pine litter inputs may affect productivity of MPB streams
Inorganic nutrients	- inorganic nitrogen and phosphorous availability affects stream productivity and organic matter processing	- nitrogen water chemistry - phosphorous water chemistry - conductivity - discharge	- periphyton - organic matter processing - invertebrate production	Short to mid-term	No changes detected, riparian may have minimal role and may be more a watershed level process	**LOW**	All streams	Changes in watershed vegetation and soil disturbance from salvage activities may affect soil and stream nutrients
Dissolved organic matter	- natural sunscreen to protect against UV exposure of biota - nutrient for microbial communities	- dissolved organic carbon - UV absorbtion	- shade and direct solar radiation exposure - temperature - litterfall - inorganic nutrients	Short to mid term	No changes detected, riparian may have minimal role and may be more a watershed level process	**LOW**	All streams	Changes in watershed vegetation and soil disturbance from salvage activities may affect soil and stream DOM inputs
Periphyton	-organic matter for invertebrate production	- periphyton accrual rates and maximum biomass	- invertebrates - light - temperature - suspended sediment - inorganic nutrients	Short to mid term	Yes/No, remained low in some streams (nutrient limited), increased in others (light limited)	**LOW**	All streams	Changes in stream nutrients and shade will determine response of periphyton communities
Invertebrate drift production	- primary food source for resident fish - production for downstream export to fish habita	- 24 hr drift nets	- benthic invertebrates - water temperature - discharge - fish growth and health	Short to mid term	Yes/No, complex changes in some streams	**MODERATE**	All streams	Productivity affected by changes in stream shade, nutrients, litterfall and periphyton.
Benthic Invertebrates	- source of invertebrate drift - instream processing of organic matter	- Serber sampling	- shade and UV radiation - nutrients - litterfall - periphyton	Short to mid-term	Yes/No, complex changes in some streams	**MODERATE**	All streams	Productivity affected by changes in stream shade, nutrients, litterfall and periphyton.
Fish	- headwater streams are important spawning and rearing habitats	- fish traps, length-weight	- stream productivity - invertebrate drift - stream habitat and cover - water temperatures	Short to mid-term	Ephemeral use of the streams complicates assessment	**MODERATE**	All fish bearing streams	Productivity affected by changes in stream shade, nutrients, litterfall and periphyton.

[1] Short term = 0 to 5 yrs
Medium term = 5 to 20 yrs
Long term = 20 to 80 yrs