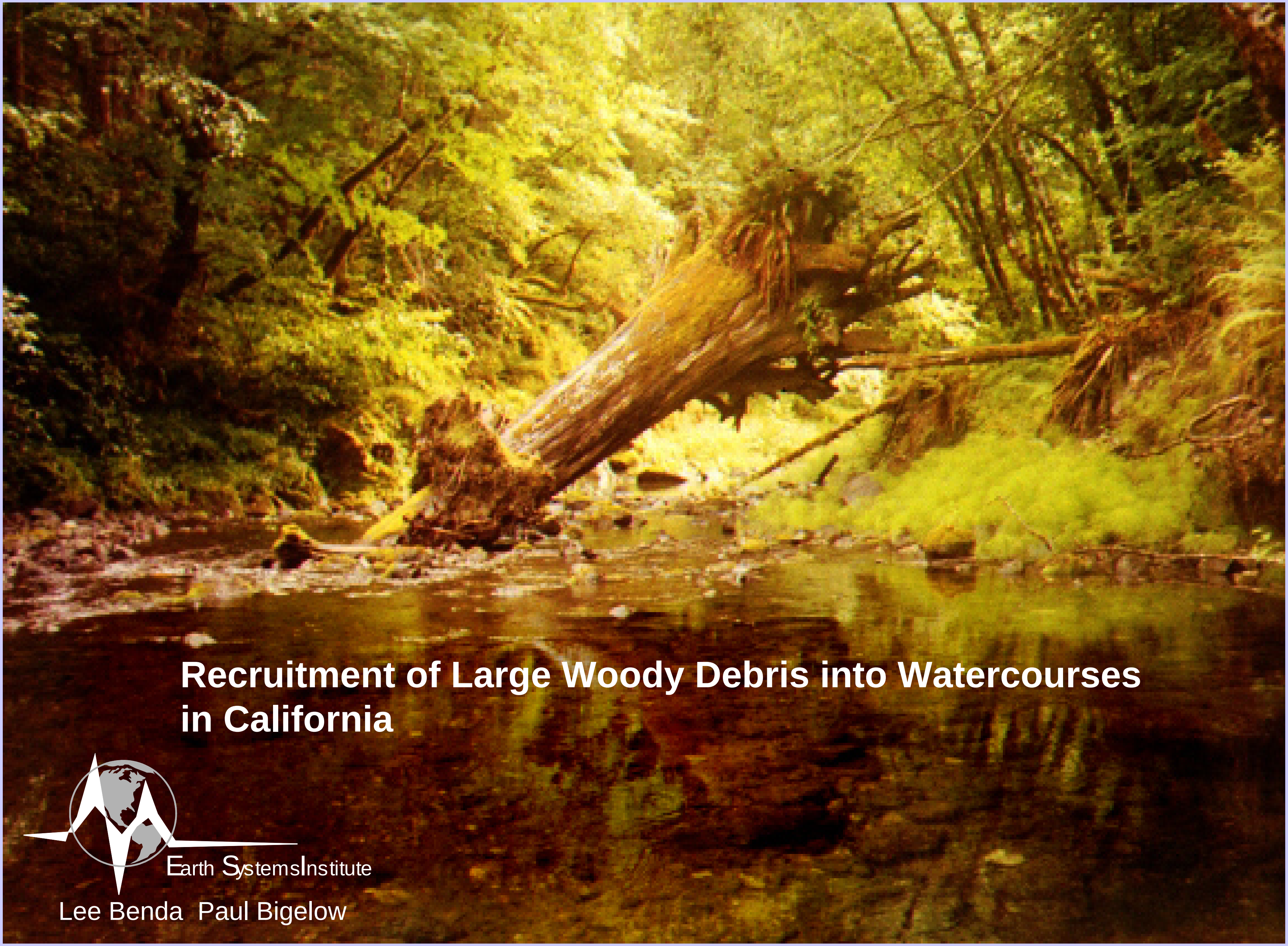


Recruitment of Large Woody Debris into Watercourses in California

Earth Systems Institute

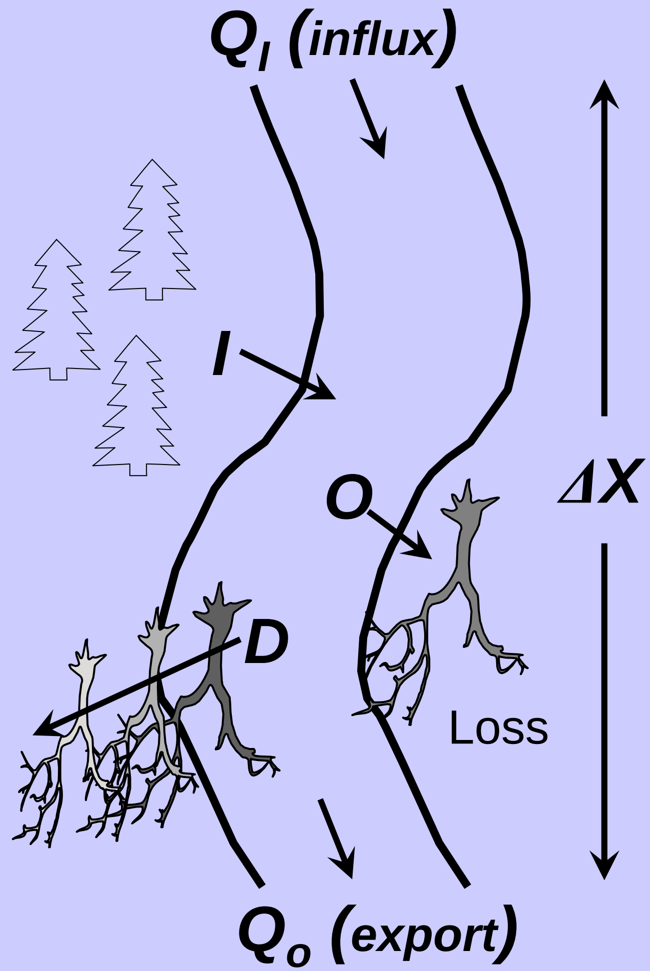
Lee Benda Paul Bigelow

METHODS: Wood Budgeting

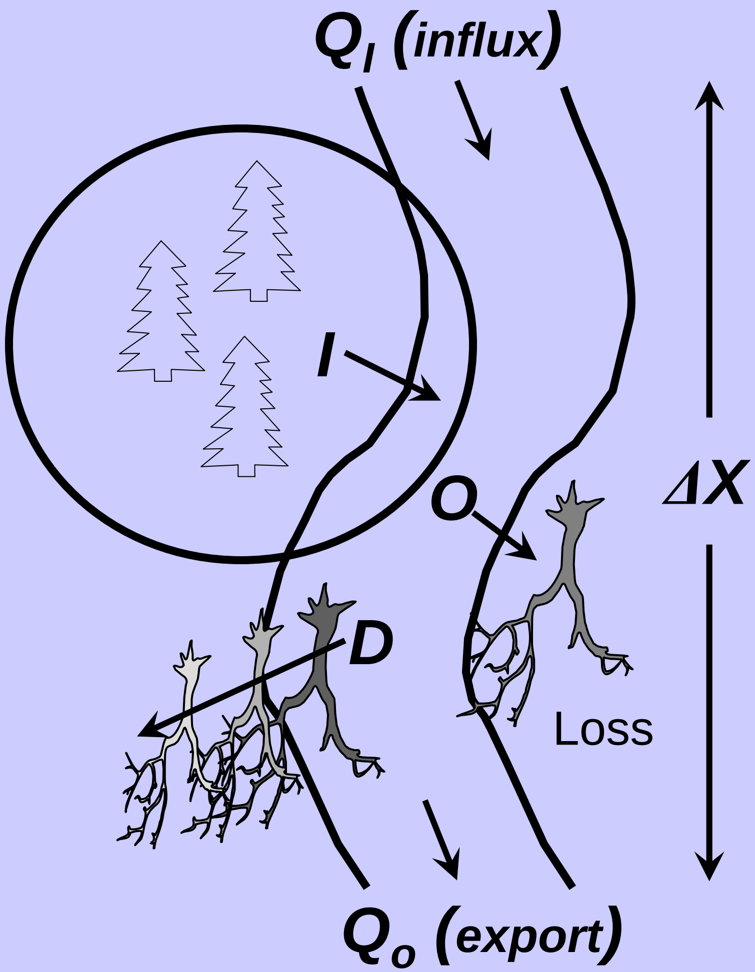
Wood Budgeting is Analogous to Sediment Budgeting.

<u>Sediment budgeting</u> estimates the processes and rates of erosion, sediment transport, and sedimentation (Dietrich and Dunne 1978; Dietrich et al. 1985).

<u>Wood budgeting</u> estimates the processes and rates of wood recruitment, storage, transport, and decay (Benda and Sias 1998; Martin and Benda 2001; Benda et al. 2003).



LWD Mass Balance



FIELD METHODS:

-Continuous measurements along reaches 300 to 1000 m in length;

-Inventory all wood (greater than 10 cm diameter, 3 m length) in terms of piece volume, specify conifer/deciduous species;

-inventory sources of wood recruitment when possible (mortality, bank erosion, landsliding, exhumed from channel bed), approximately 20% of all pieces;

-estimate age of all recruited wood by dendrochronology or decay class ;

-measure the distance of recruited wood to sources on stream banks (slope distance);

-collect data on wood transport (includes interjam spacing, proportion of wood mobile (pieces < channel width); jam age);

-inventory channel hydraulic geometry, substrate size, streamside landslide characteristics, pool formers.

Field Team: Paul Bigelow, Kevin Andras

Types of Questions

1) Relative importance of different recruitment processes (by rates)

2) Effects of past timber harvest

3) Spatial variability (reach, watershed, province)

4) Effect of different climates, topographies, and basin sizes?

Different Recruitment Agents

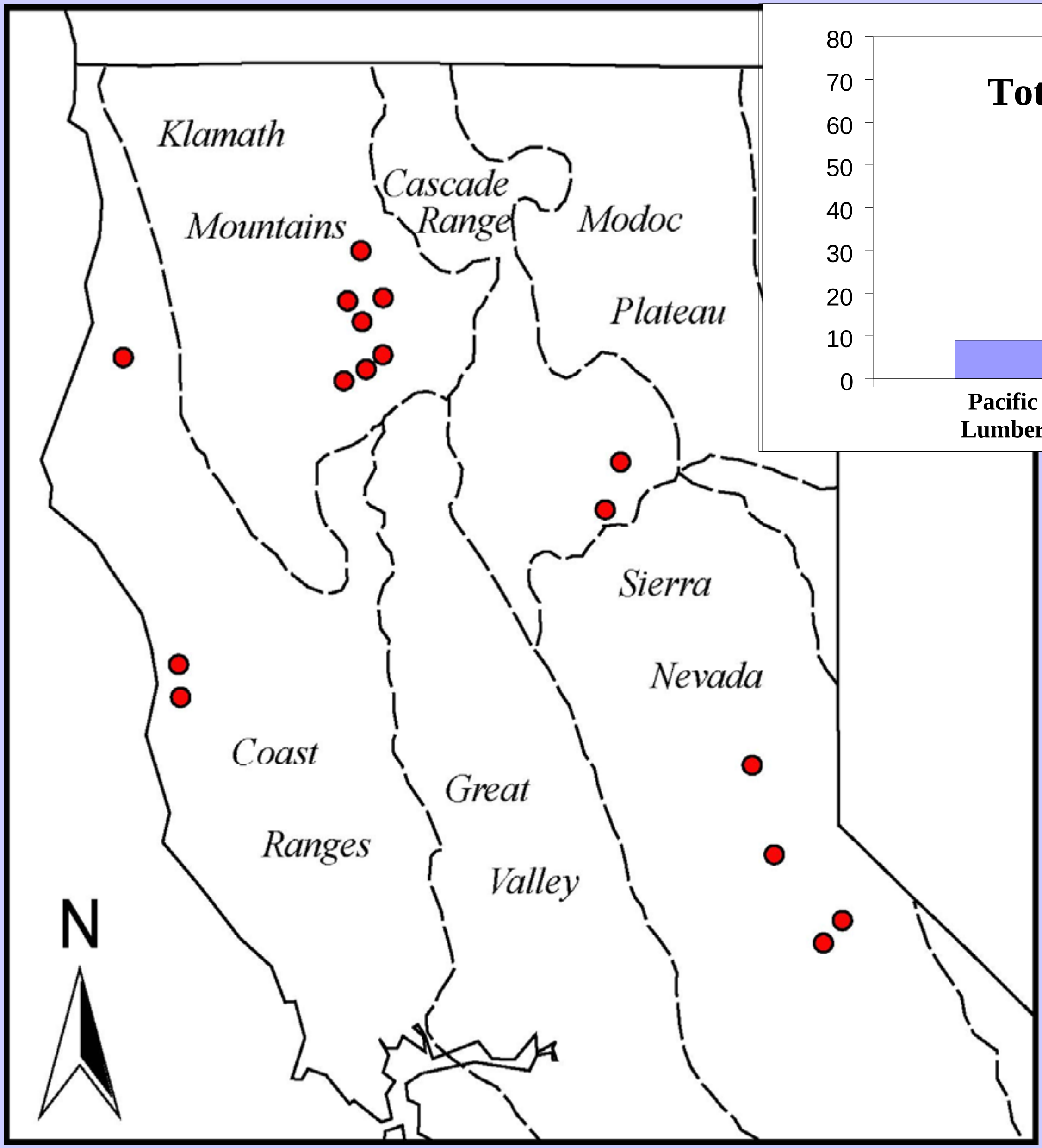
Forest growth and chronic mortality

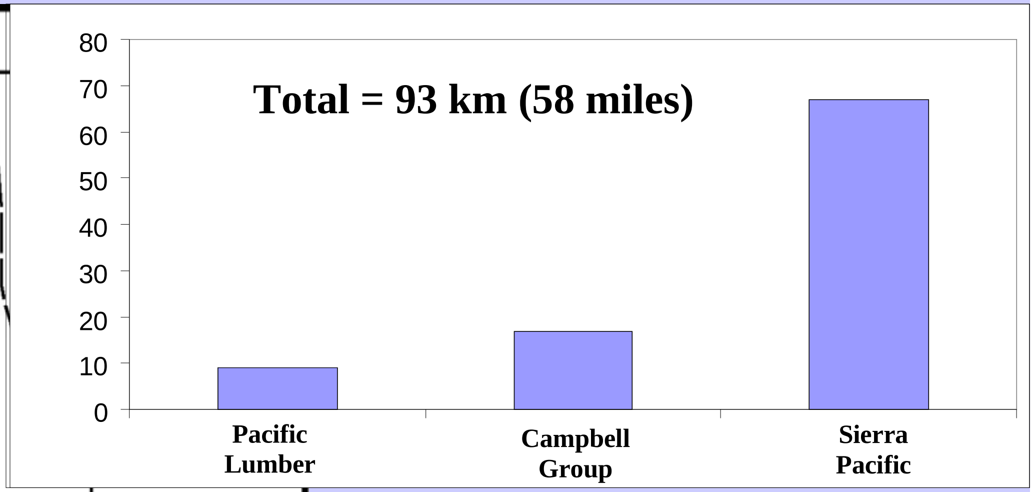
Bank Erosion

Landsliding / Debris Flow

Fires (not included)

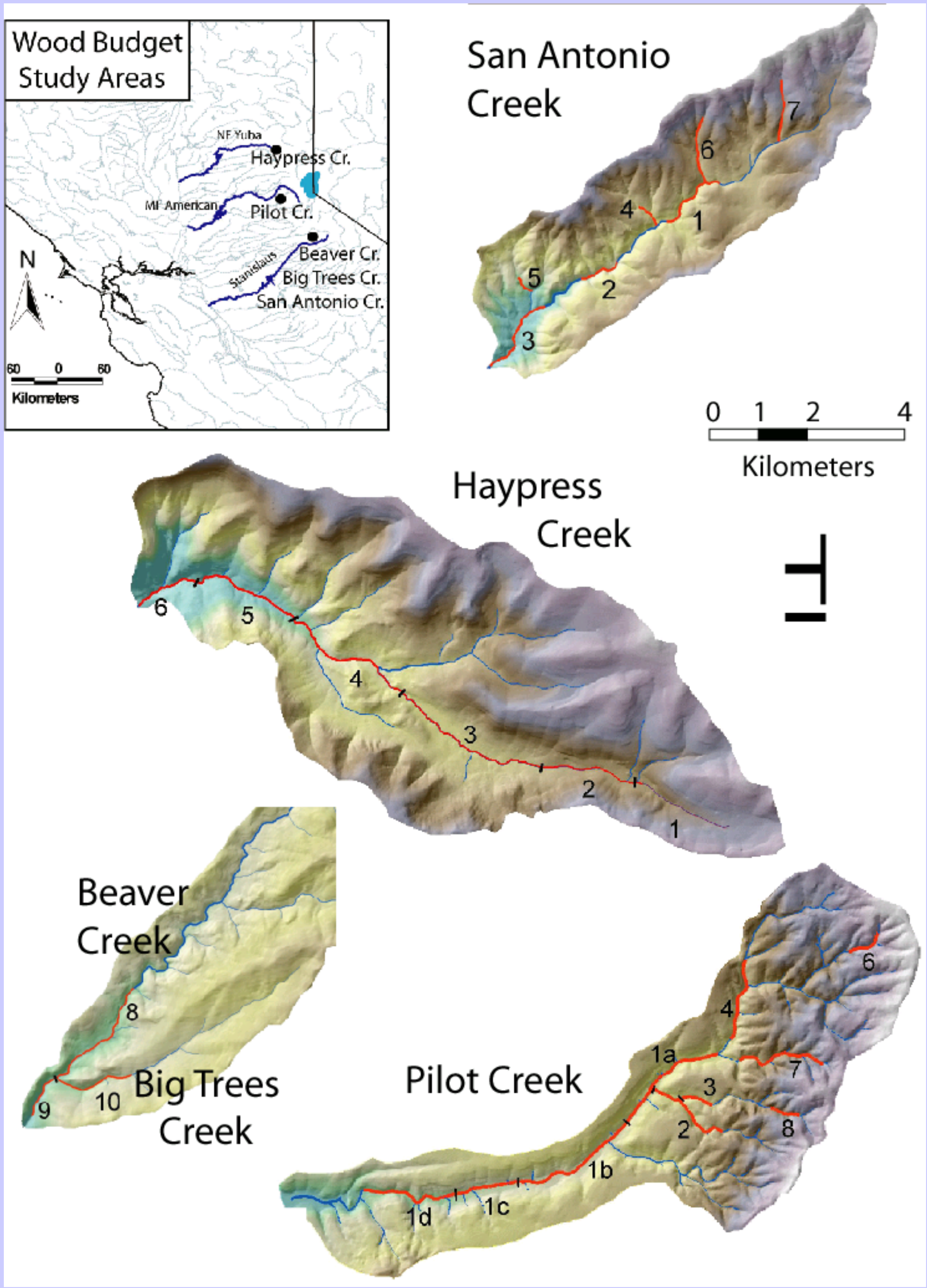
California Wood Study Locations



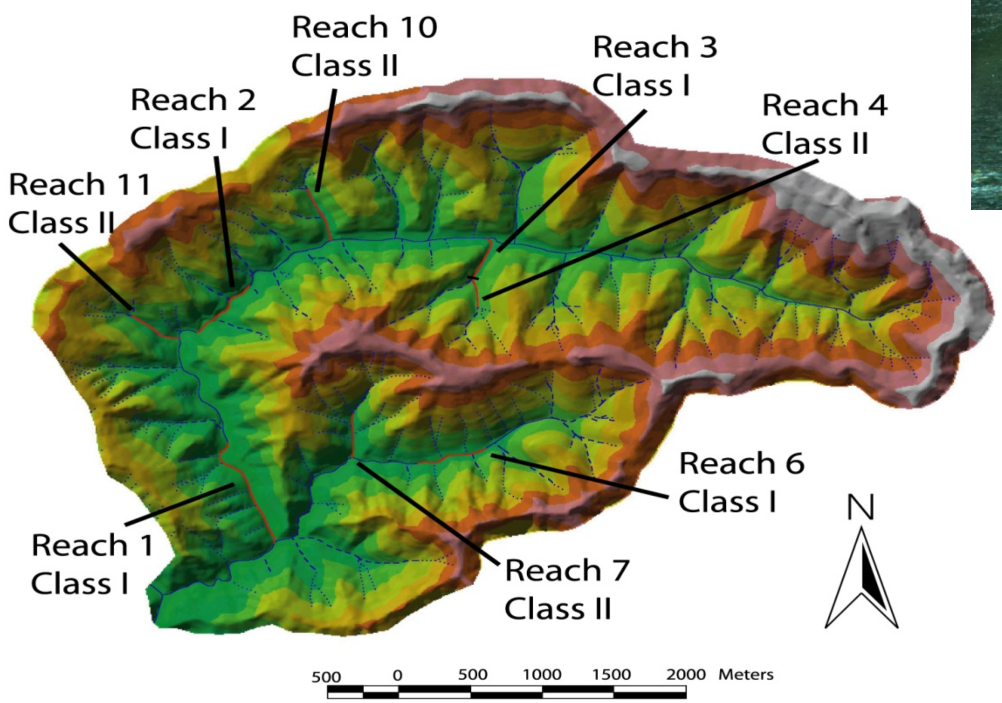


Forest Type	Geomorphic Province	Watershed	Harvest Years	Age Range (yrs)	Diameter Range (ft)	Height Range (ft)	Species Composition
Managed	Coast	LNF Noyo	1900, 1960s, 1980s	20-100	6-60	30-160	Rwd-65, DF-10, WW-10, Hwds- 15
Managed	Coast	Redwood	1930s, 1980s-present	20 - 70	6-38	25-140	Rwd-65, DF-20, Hwds-15
Managed	Coast	Bear Haven	1940s 1960s-70s 1990s on	30 - 60	6-36	25-140	Rwd-55, DF-30, WW-10, Hwds-5
Managed	Sierras	San Antonio	1920s - 1930s 1950s-present	30-85	2-36	30-180	PP-20, SP-15, WF-20, IC-35, Hwds-10
Managed	Sierras	Pilot	1900s - 1930s 1960s-present	30-110	2-50	30-200	PP-35, SP-10, WF-35, DF- 6, IC-13, Hwds-1
Managed	Cascades	Judd	1870s-1900s 1960s-present	30-100	2-36	30-125	PP-35, SP-10, WF-35, DF- 6, IC-13, Hwds-1
Less Managed	Klamaths	SF Indian	1950s - present	30-200+	2-36	30-140	PP-09, SP-03, WF-06, DF- 35, IC-02, Hwds-45
Less Managed	Klamaths	Skunk Gulch	1950s - present	30-200+	2-34	30-170	PP-10, SP-02, WF-04, DF- 24, MC-01, Hwds-60

Example Study Site

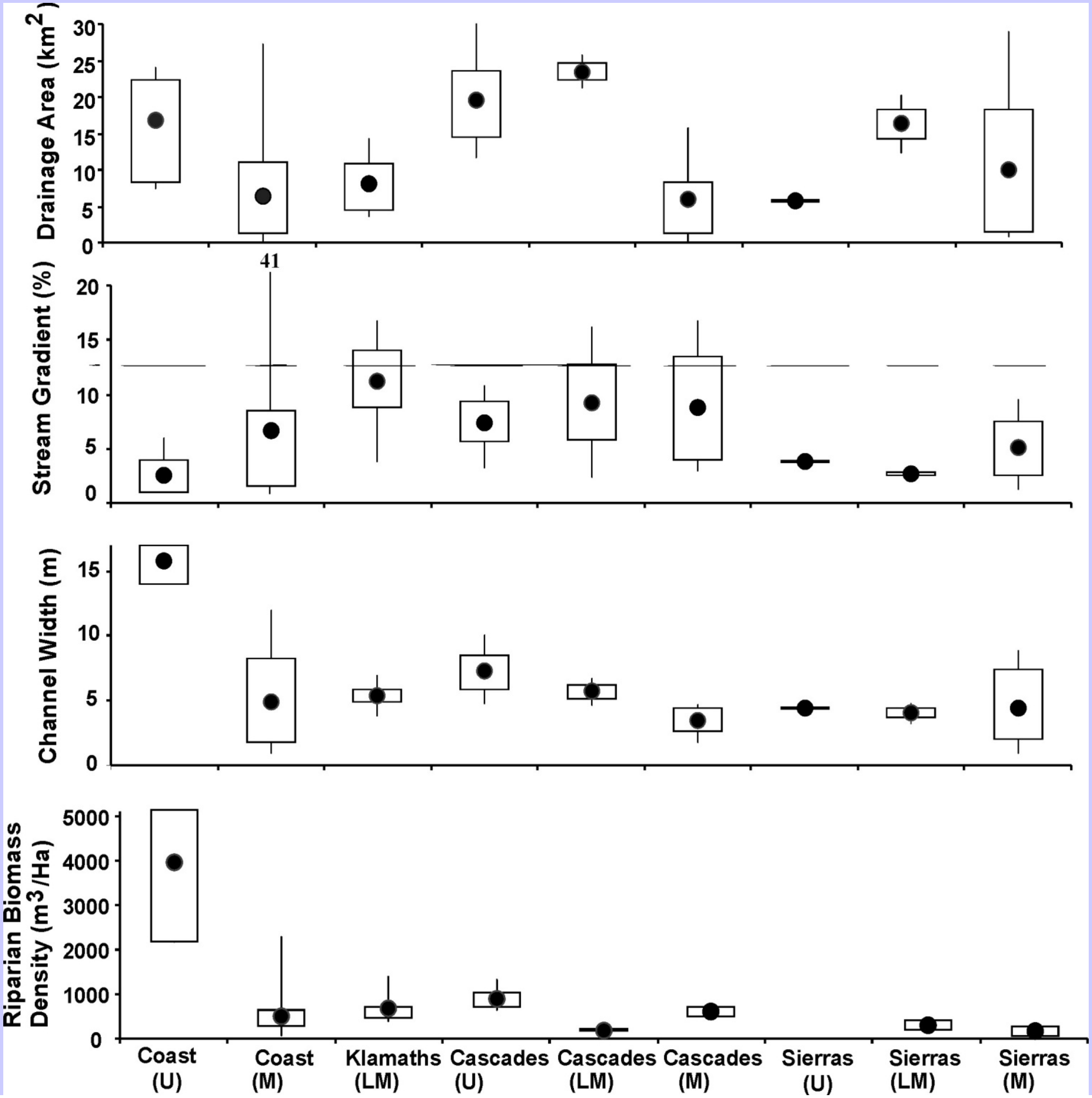


Target: Primarily Class I and II Streams

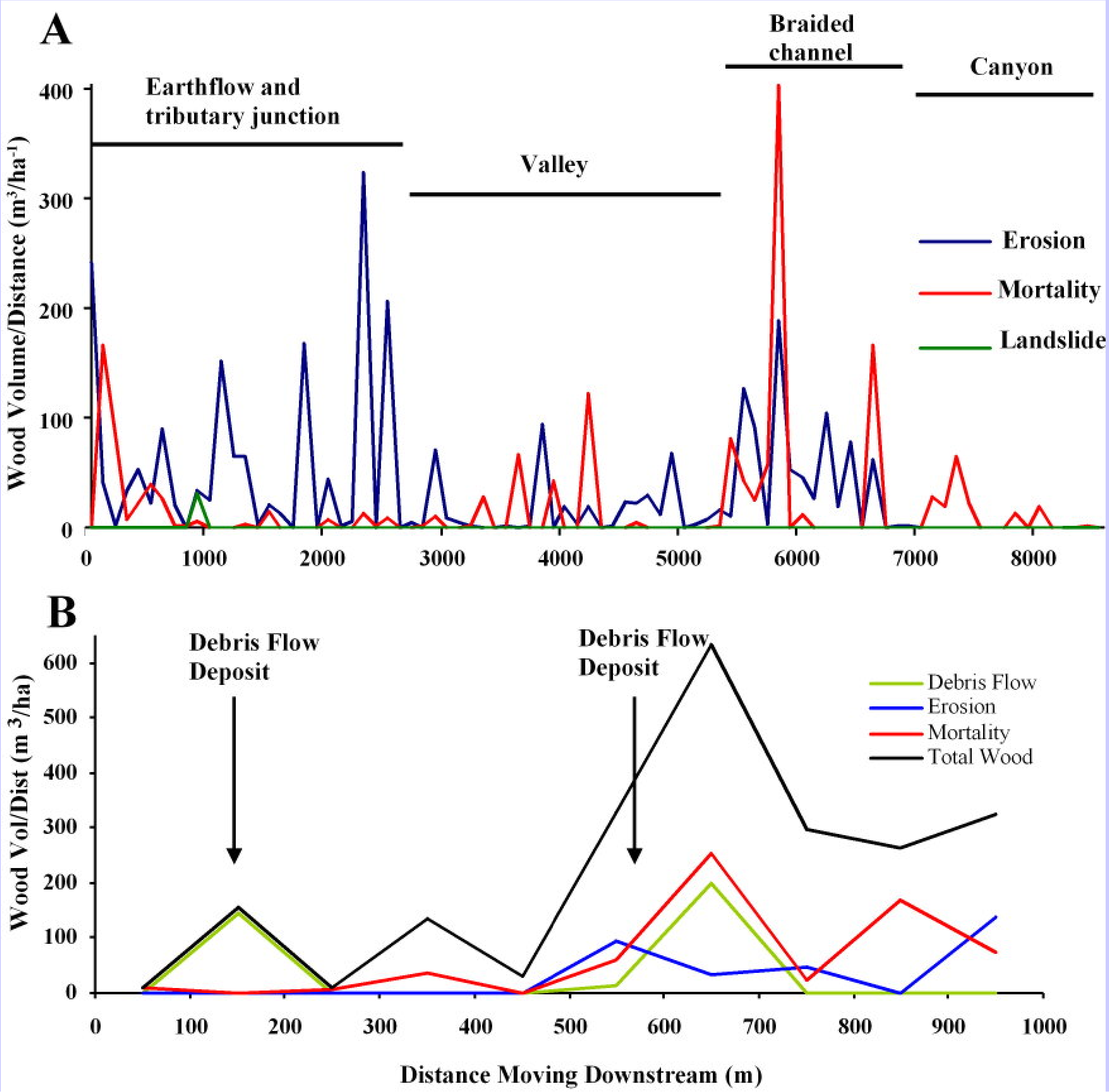


Bear Haven Wood Budget
Study Reaches

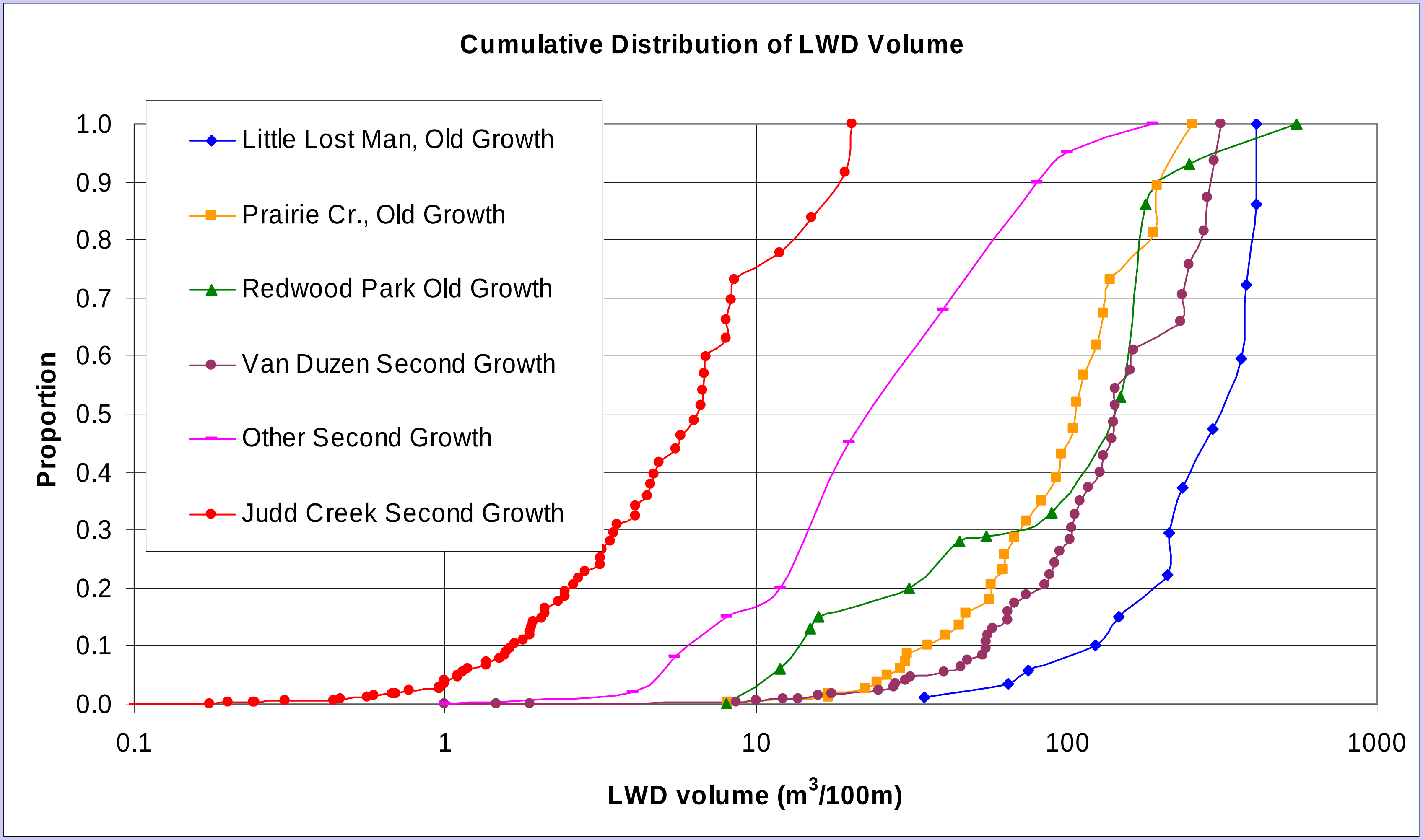
Sample reach physical properties



Results: Spatial Variability in total wood storage, driven by recruitment process

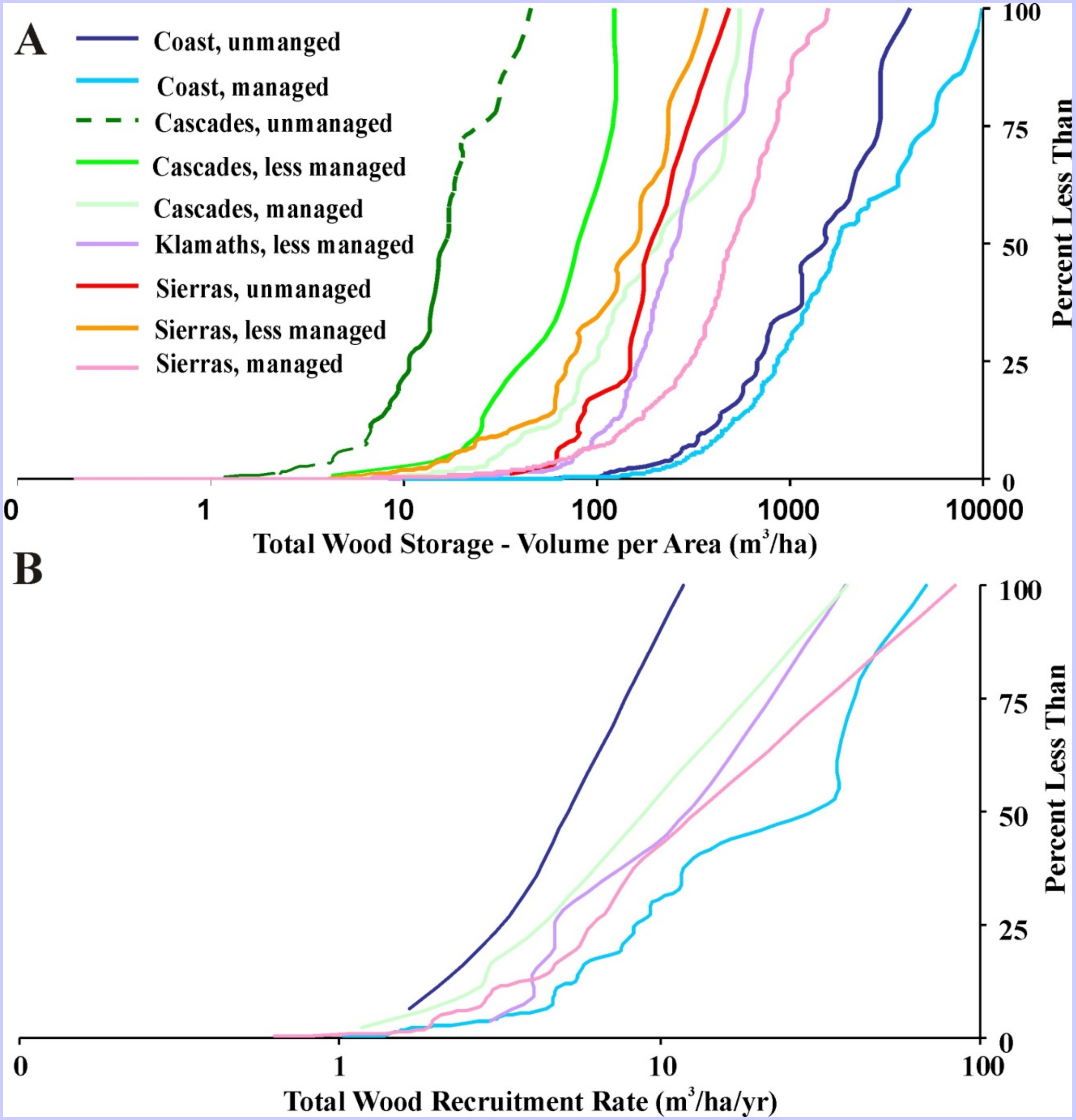


Total Wood Storage



Historical logging debris can be a significant source of wood in second growth forests (mostly coastal)

Total Wood Storage: Comparison Across Regions



Southern Cascades **Trinity** **Coast**

Less Wood --------------------More Wood-----------Most Wood

Woody debris residence time

Geomorphic Province and Forest Management	Residence Time (years)
Coast Unmanaged	168
Coast Managed	71
Klamaths Less Managed	19
Cascades Unmanaged	2
Cascades Less Managed	6
Cascades Managed	13
Sierras Unmanaged	--
Sierras Less Managed	48
Sierras Managed	20

Residence time = total volume/recruitment rate
(assumes fluvial input = output)

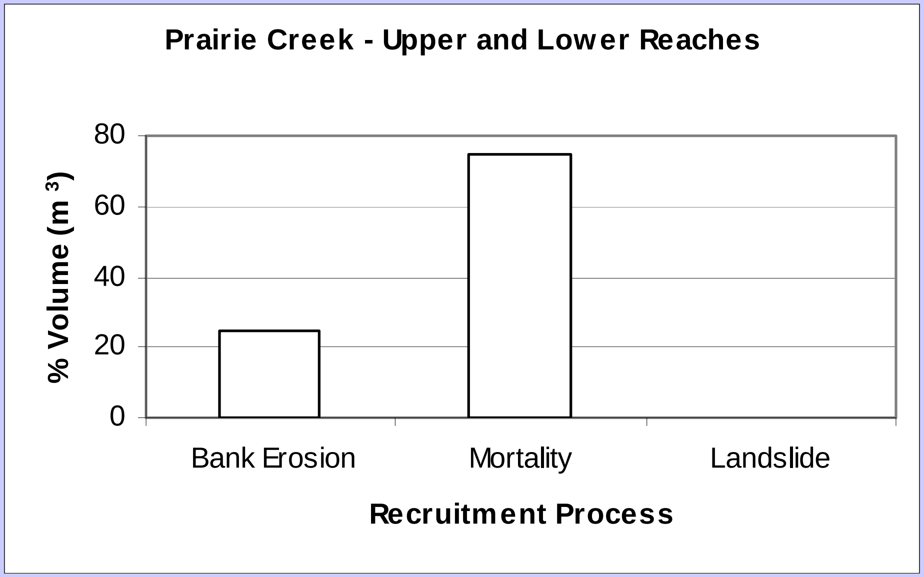
To estimate sources of wood and to calculate rates of wood recruitment (m^3/ha/yr) requires identifying the source of each piece (mortality, bank erosion, landslide)

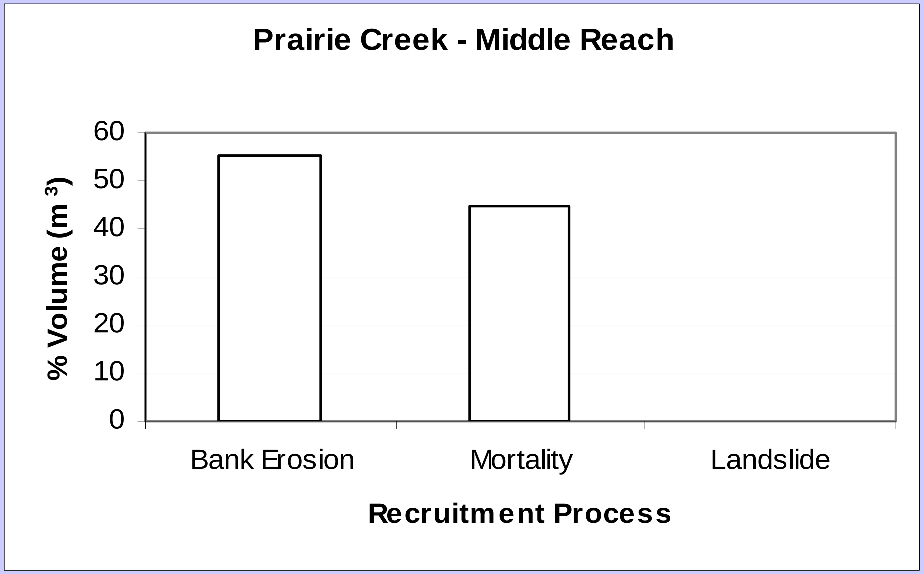
Only a portion of wood pieces could be linked to a recruitment process (range 20 - 60%, ave. 46%)

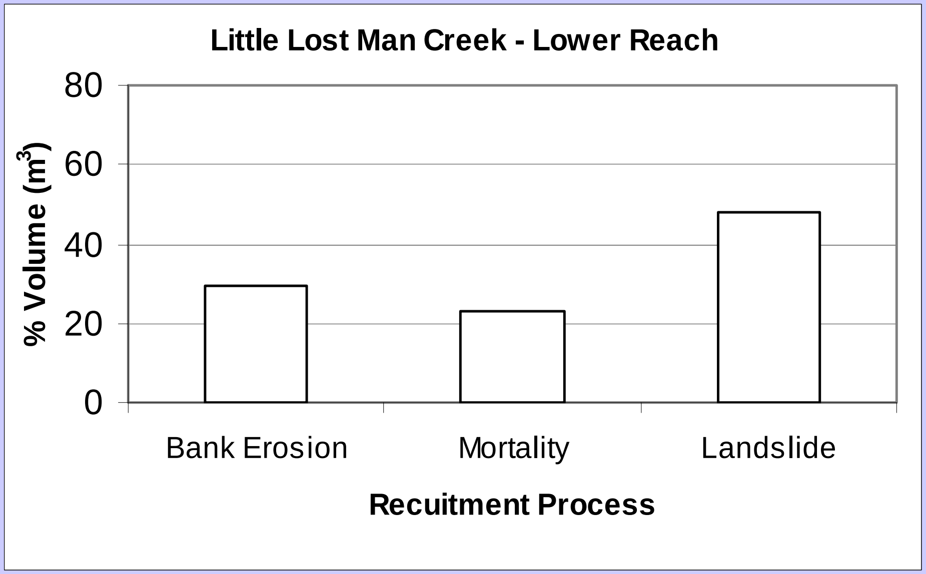
The subsample serves as an index of the entire population of pieces

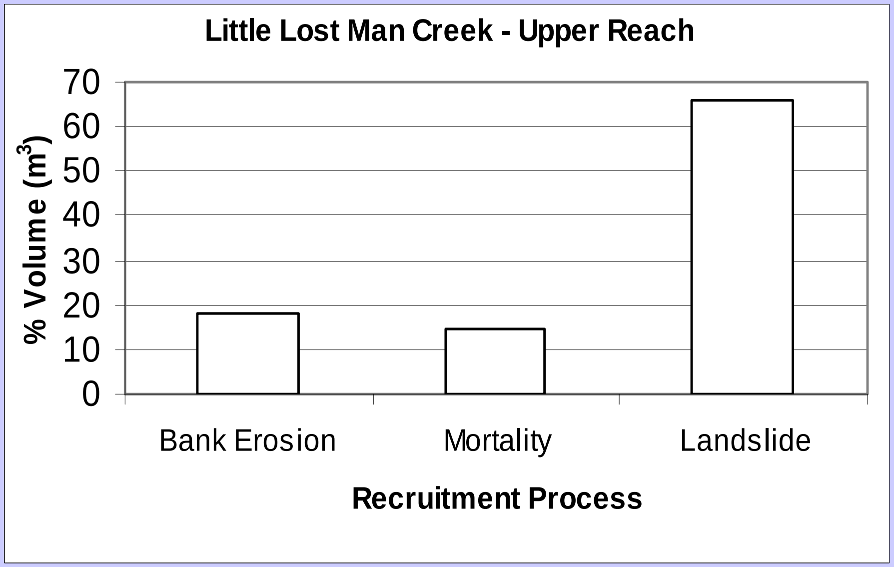
Wood Recruitment Sources

Redwood Forests: Mature (never harvested)

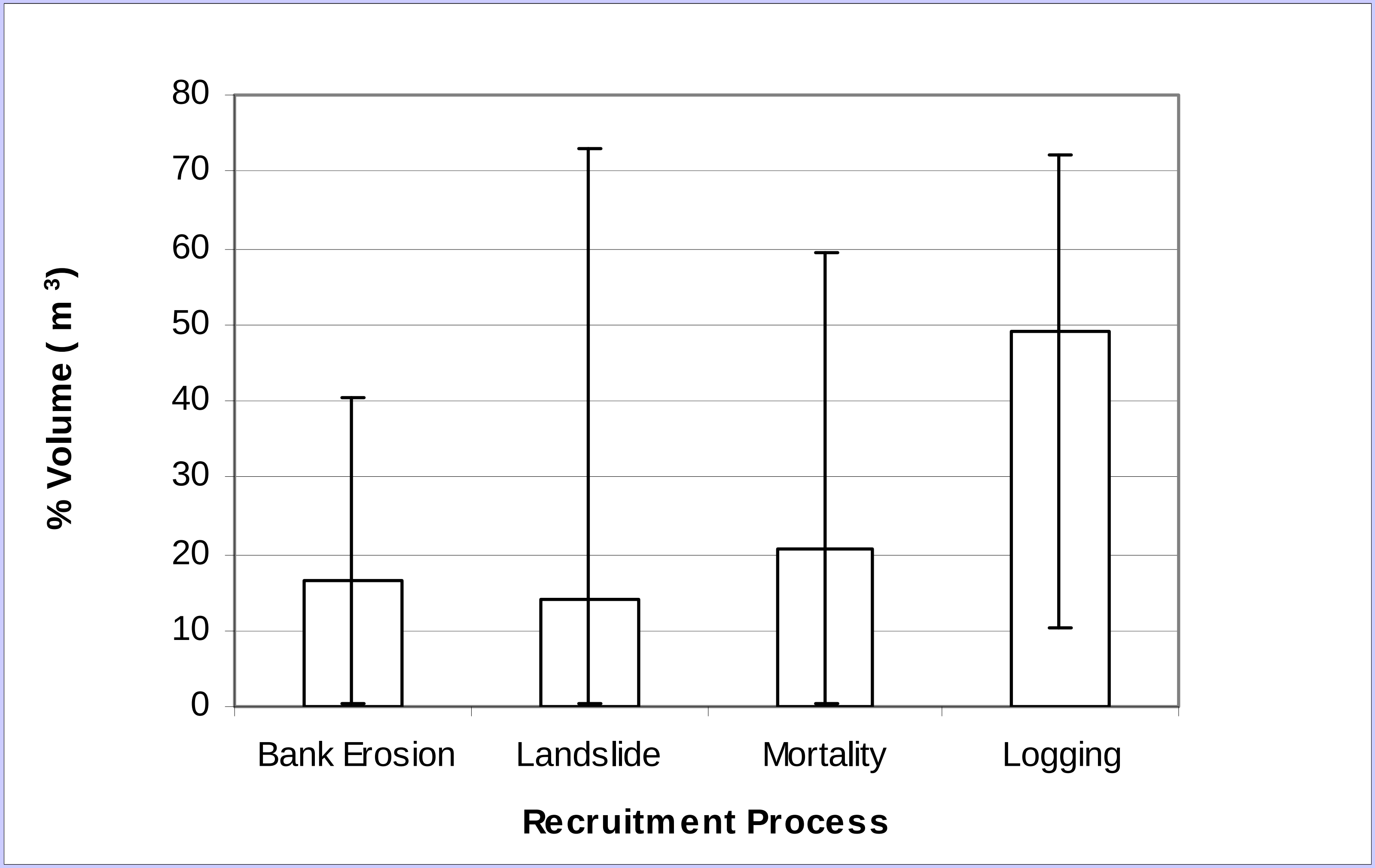




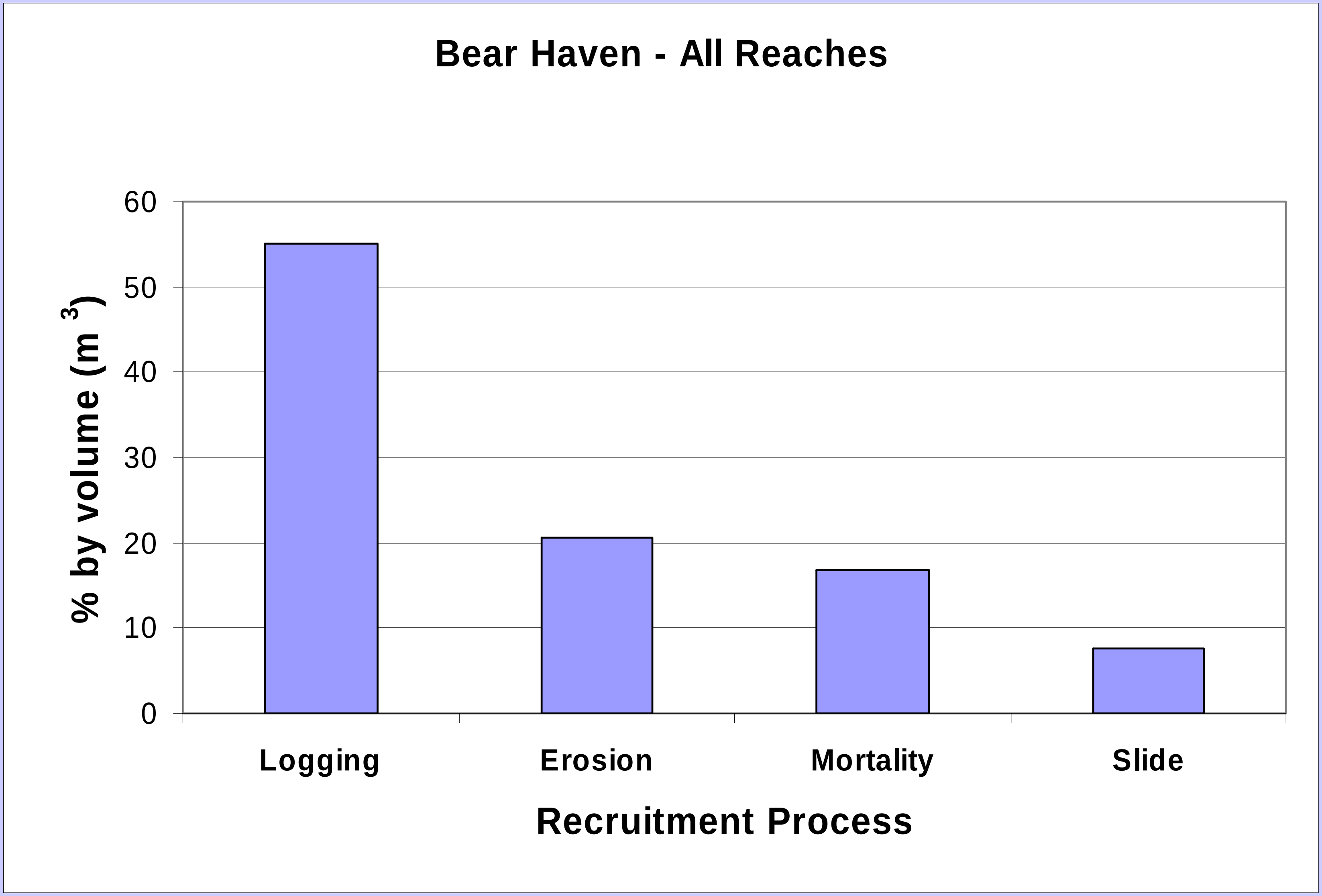




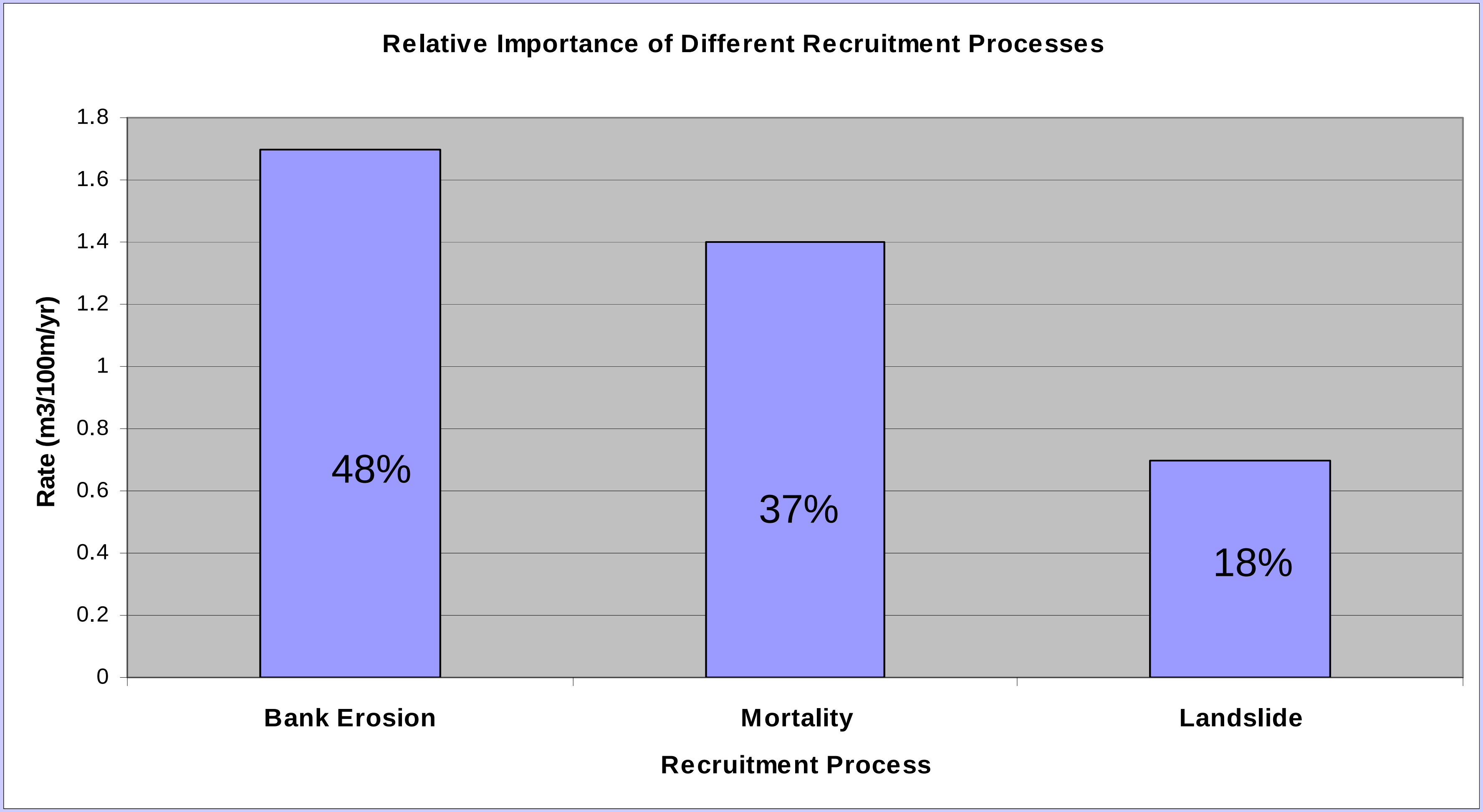
Redwood Forests: Second Growth



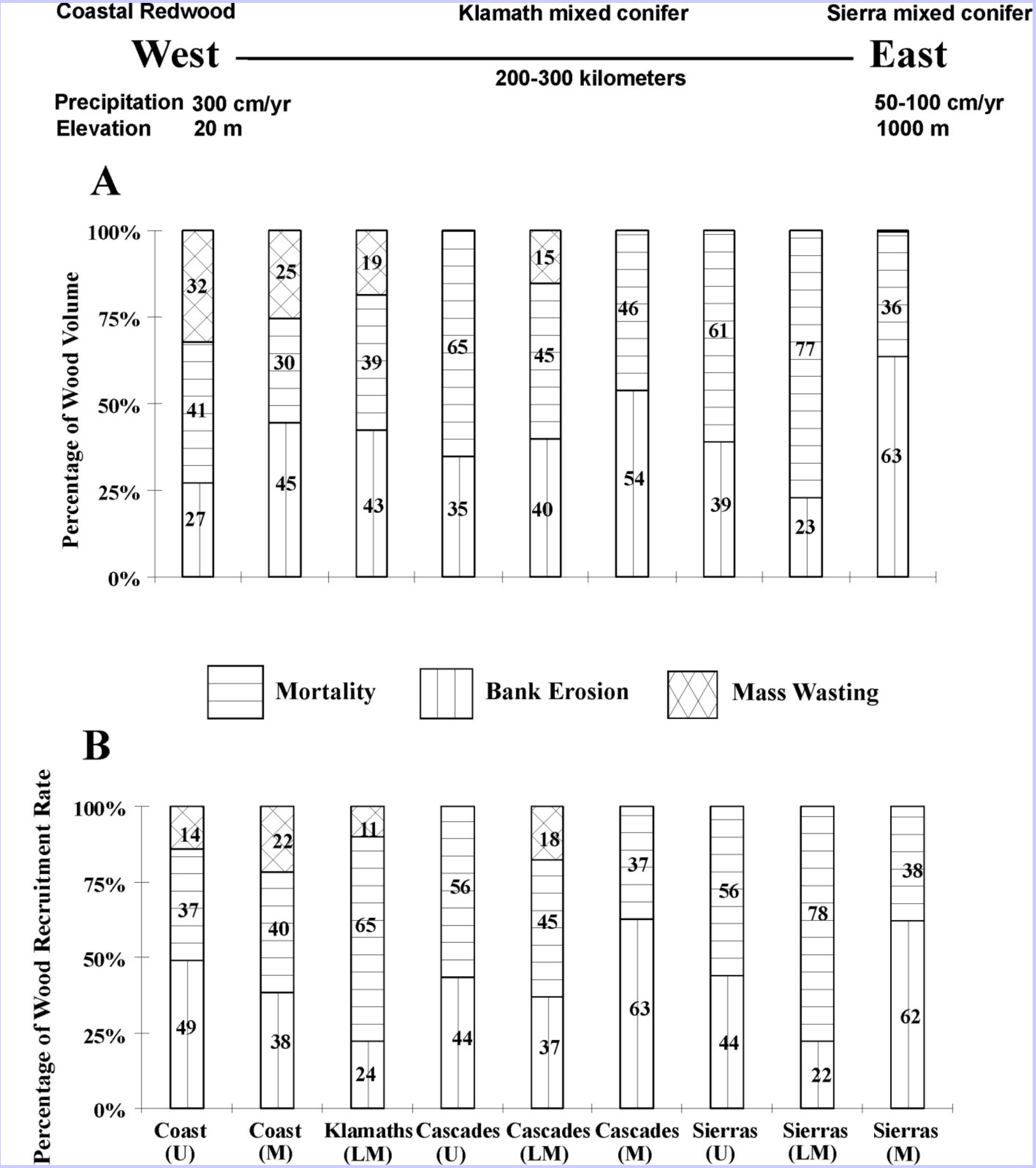
Mendocino Coast: Douglas Fir/Redwood Forests: Second Growth



Mendocino Coast: Second Growth (logging debris not included)

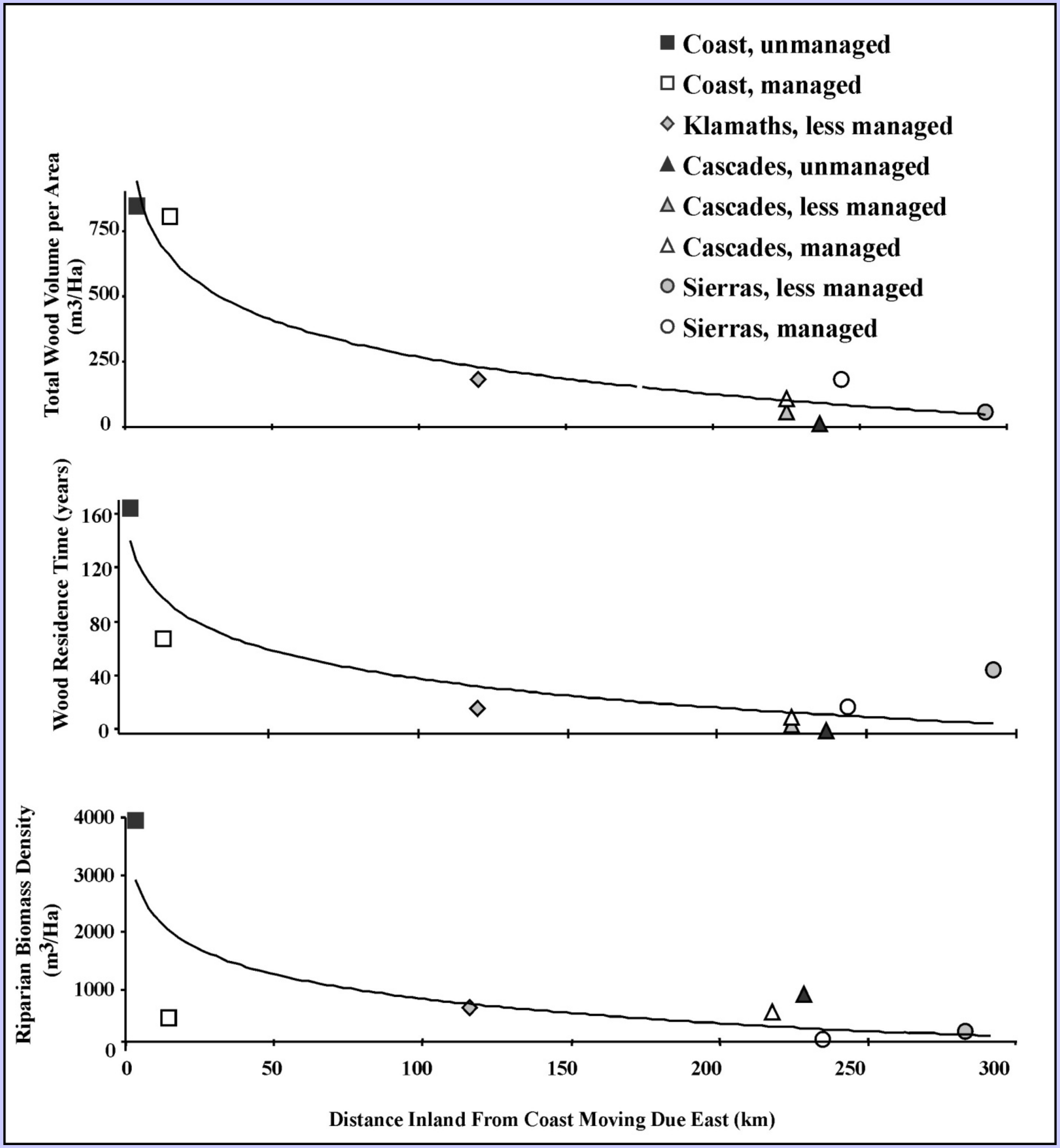


All Study Sites

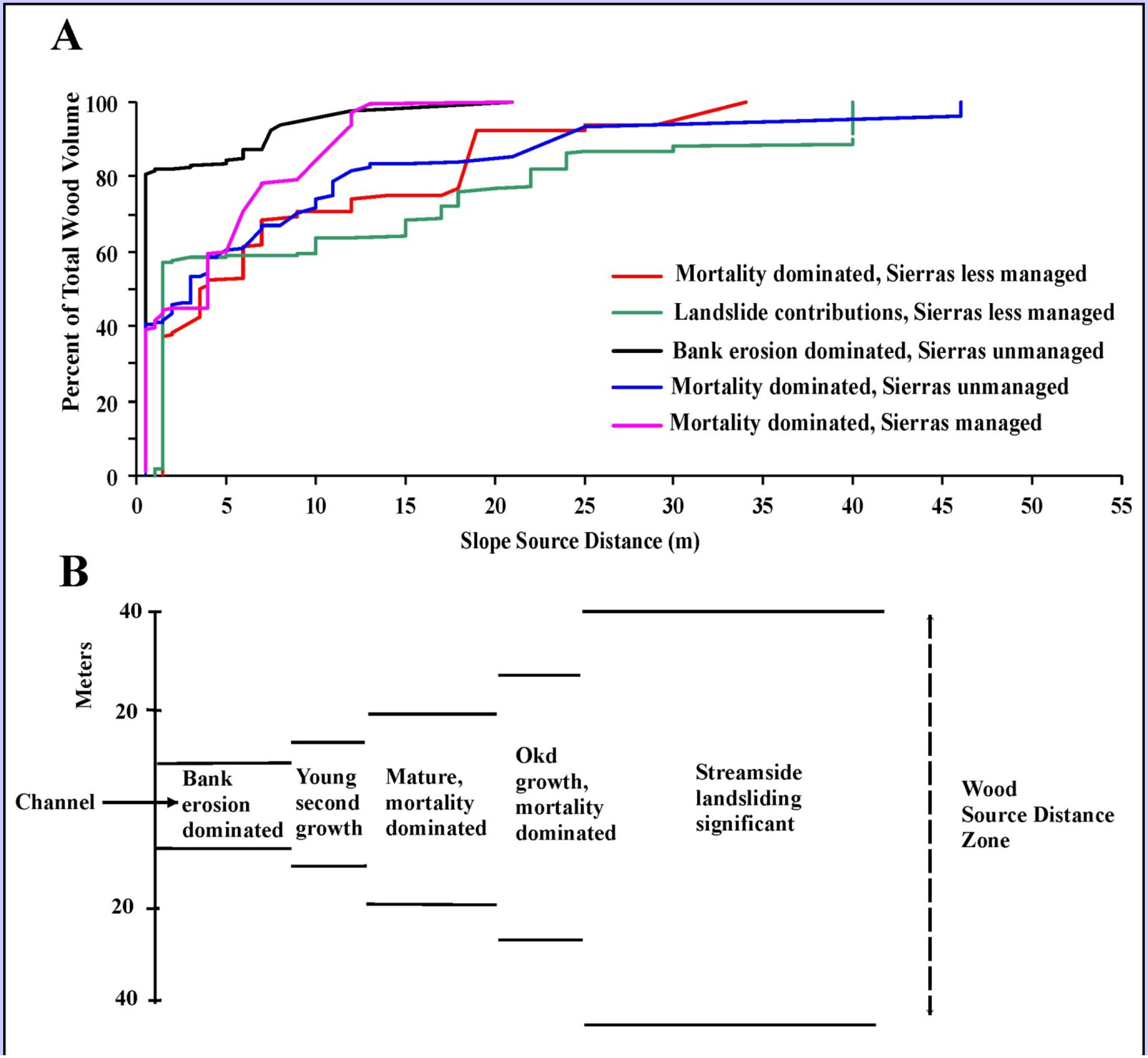


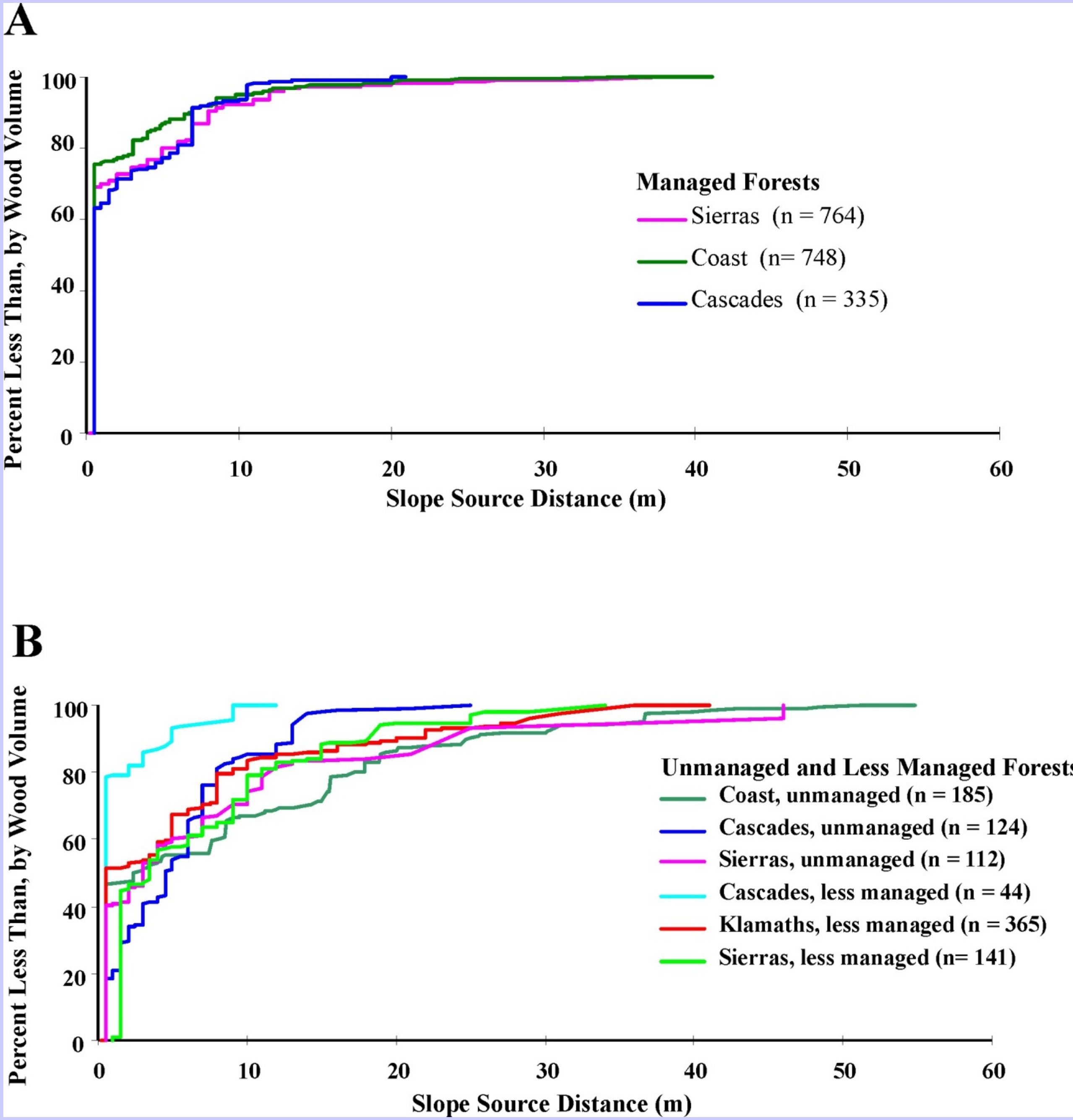
“U” = managed
“LM” = less managed
“U” = unmanaged (Park)

West – east gradient in total biomass, residence time and total wood storage



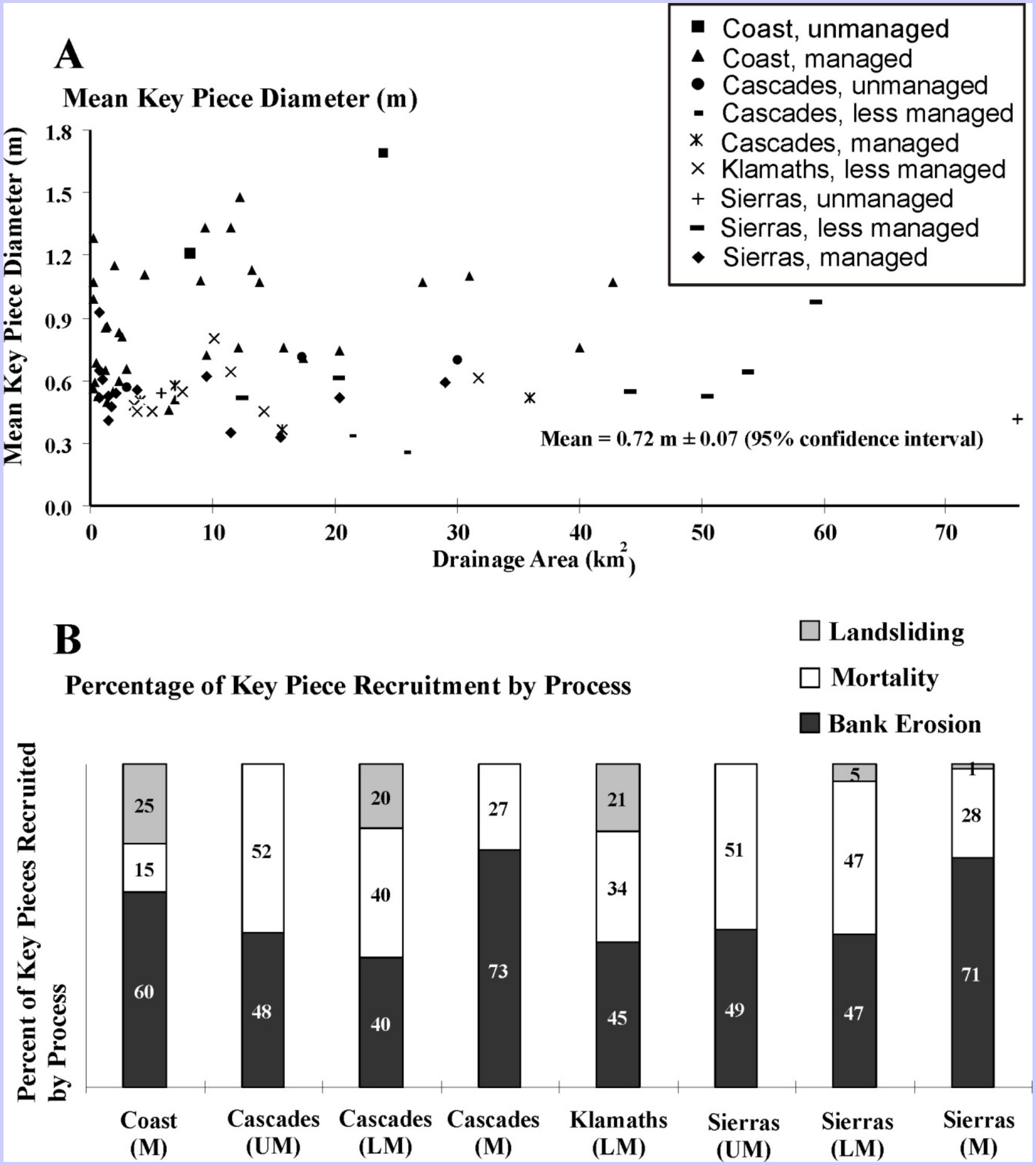
The distance to sources of wood.

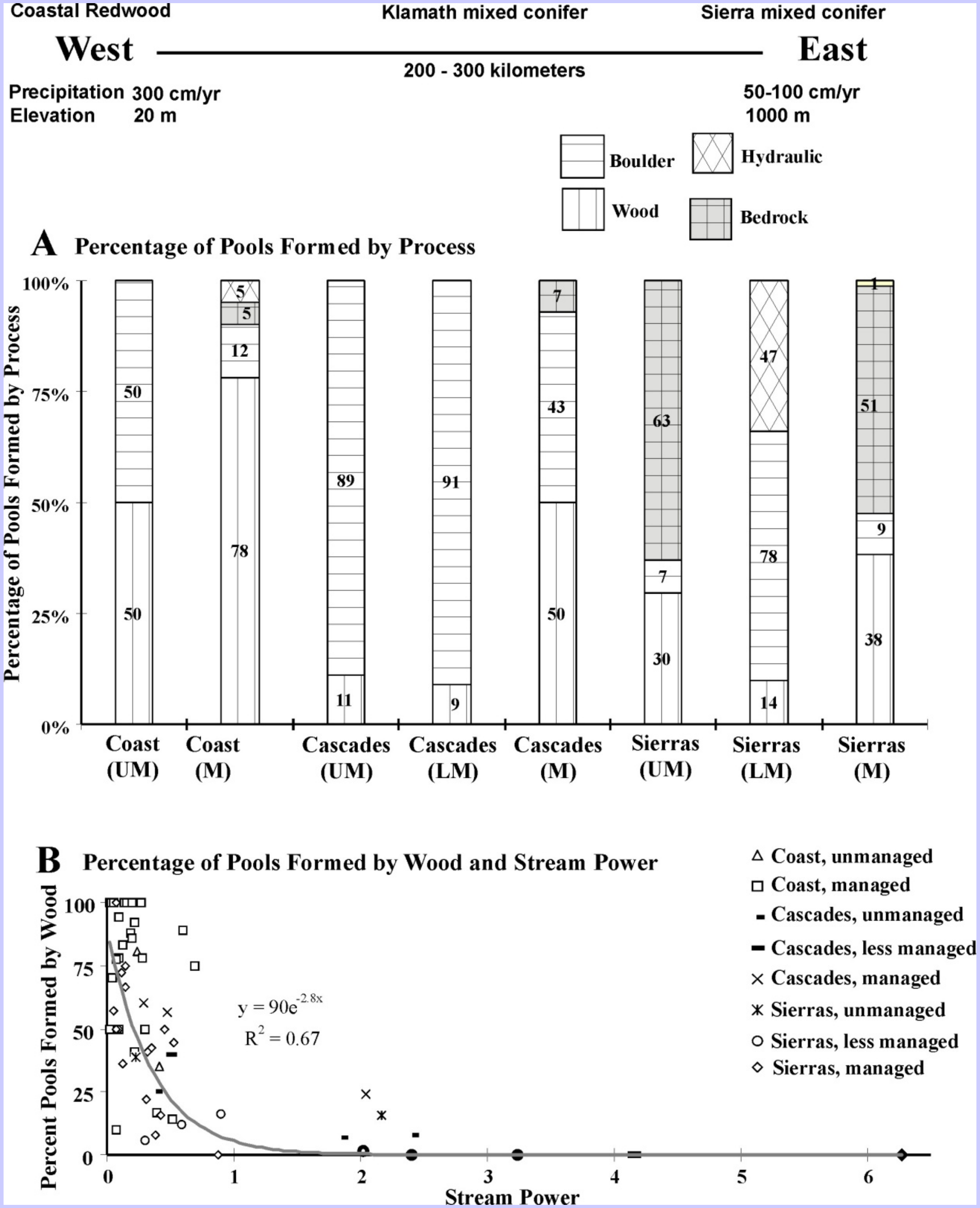



A
Percent Less Than, by Wood Volume
Slope Source Distance (m)
Managed Forests
Sierras (n = 764)
Coast (n= 748)
Cascades (n = 335)
B
Percent Less Than, by Wood Volume
Slope Source Distance (m)
Unmanaged and Less Managed Forests
Coast, unmanaged (n = 185)
Cascades, unmanaged (n = 124)
Sierras, unmanaged (n = 112)
Cascades, less managed (n = 44)
Klamaths, less managed (n = 365)
Sierras, less managed (n= 141)

Wood Function – Pool Formation

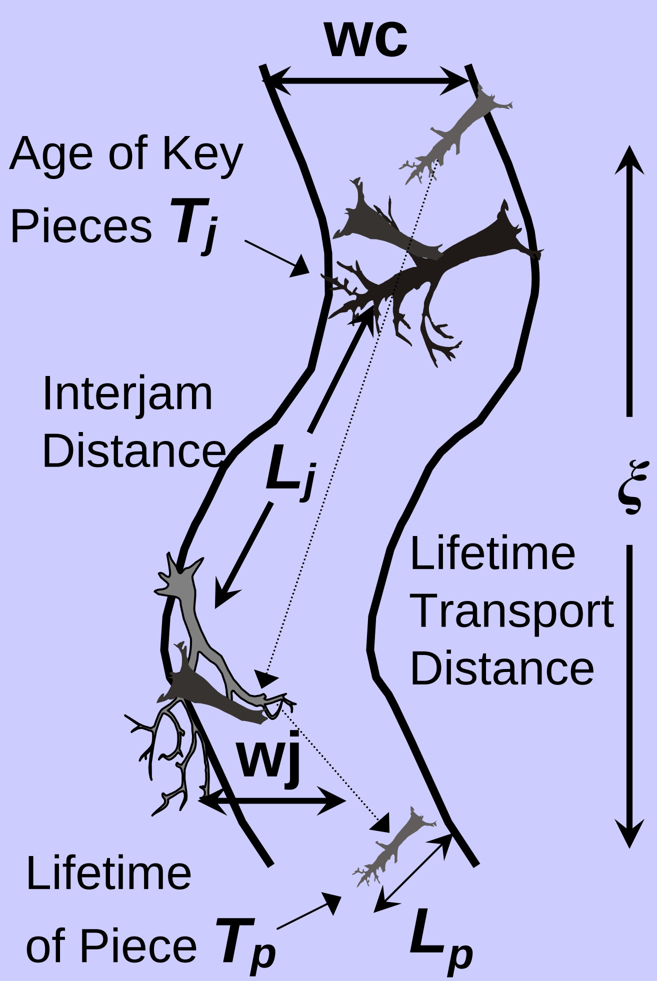
“Key” Pieces – Stable, Pool Formers


A
Mean Key Piece Diameter (m)
Coast, unmanaged
Coast, managed
Cascades, unmanaged
Cascades, less managed
Cascades, managed
Klamaths, less managed
Sierras, unmanaged
Sierras, less managed
Sierras, managed
Mean Key Piece Diameter (m)
Drainage Area (km2)
Mean = 0.72 m ± 0.07 (95% confidence interval)
B
Percentage of Key Piece Recruitment by Process
Landsliding
Mortality
Bank Erosion
Percent of Key Pieces Recruited by Process
Coast (M)
Cascades (UM)
Cascades (LM)
Cascades (M)
Klamaths (LM)
Sierras (UM)
Sierras (LM)
Sierras (M)



Coastal Redwood
Klamath mixed conifer
Sierra mixed conifer
West
East
200 - 300 kilometers
Precipitation 300 cm/yr
Elevation 20 m
50-100 cm/yr
1000 m
Boulder
Hydraulic
Wood
Bedrock
A Percentage of Pools Formed by Process
Percentage of Pools Formed by Process
100%
75%
50%
25%
0%
Coast (UM)
Coast (M)
Cascades (UM)
Cascades (LM)
Cascades (M)
Sierras (UM)
Sierras (LM)
Sierras (M)
B Percentage of Pools Formed by Wood and Stream Power
Coast, unmanaged
Coast, managed
Cascades, unmanaged
Cascades, less managed
Cascades, managed
Sierras, unmanaged
Sierras, less managed
Sierras, managed
y = 90e^-2.8x
R^2 = 0.67
Percent Pools Formed by Wood
Stream Power

Wood Transport



$Q_w(x,t) = I \; \phi \; \xi$

I = recruitment rate;

ϕ = proportion mobile;

ξ = transport distance over the lifetime of wood.

$(x,t) = L_j\,(x,t)\;\;(T_p(x,t)/T_j(x,t))^{\beta\;-1}$

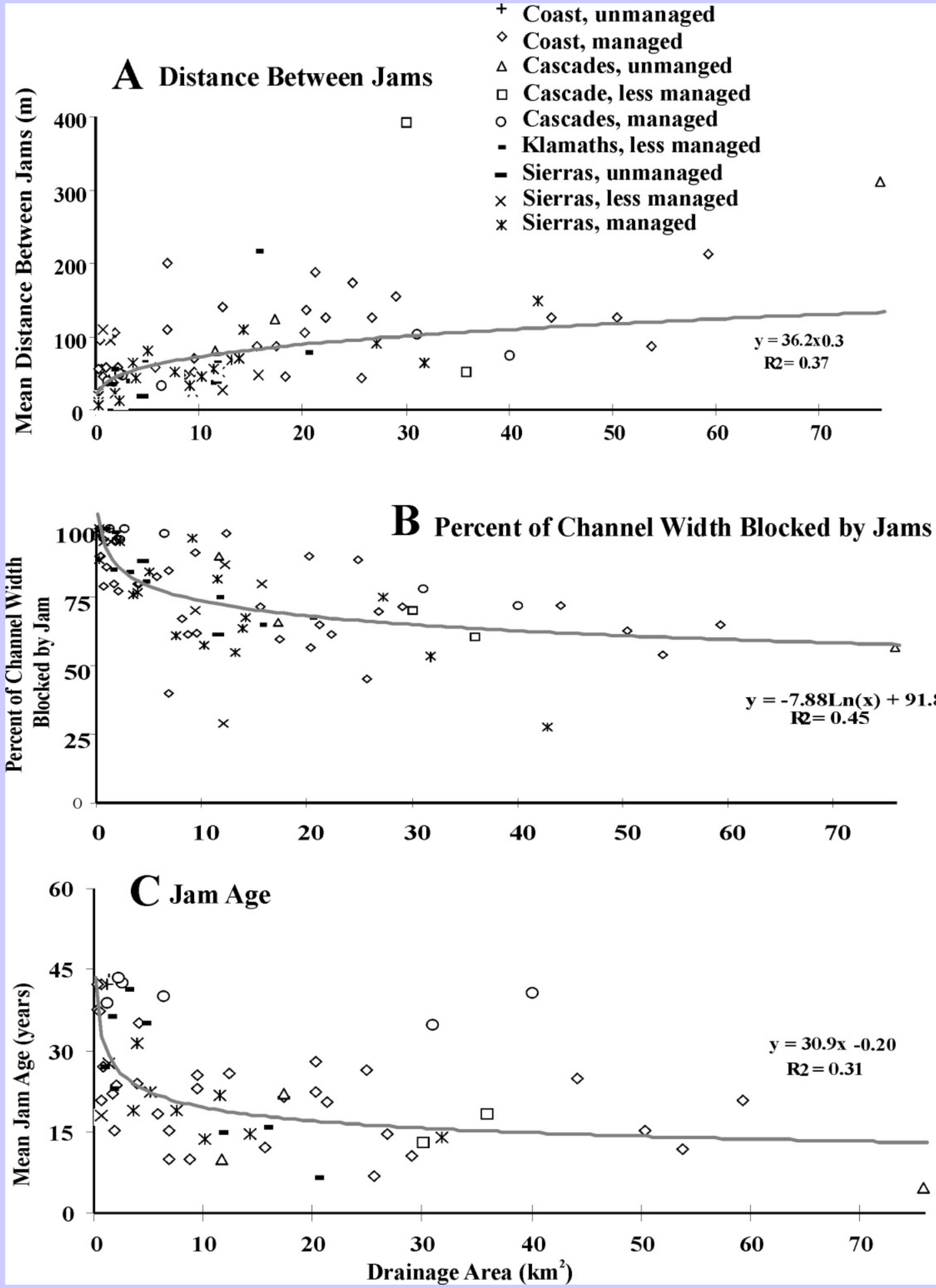
for $T_p >= T_j$,

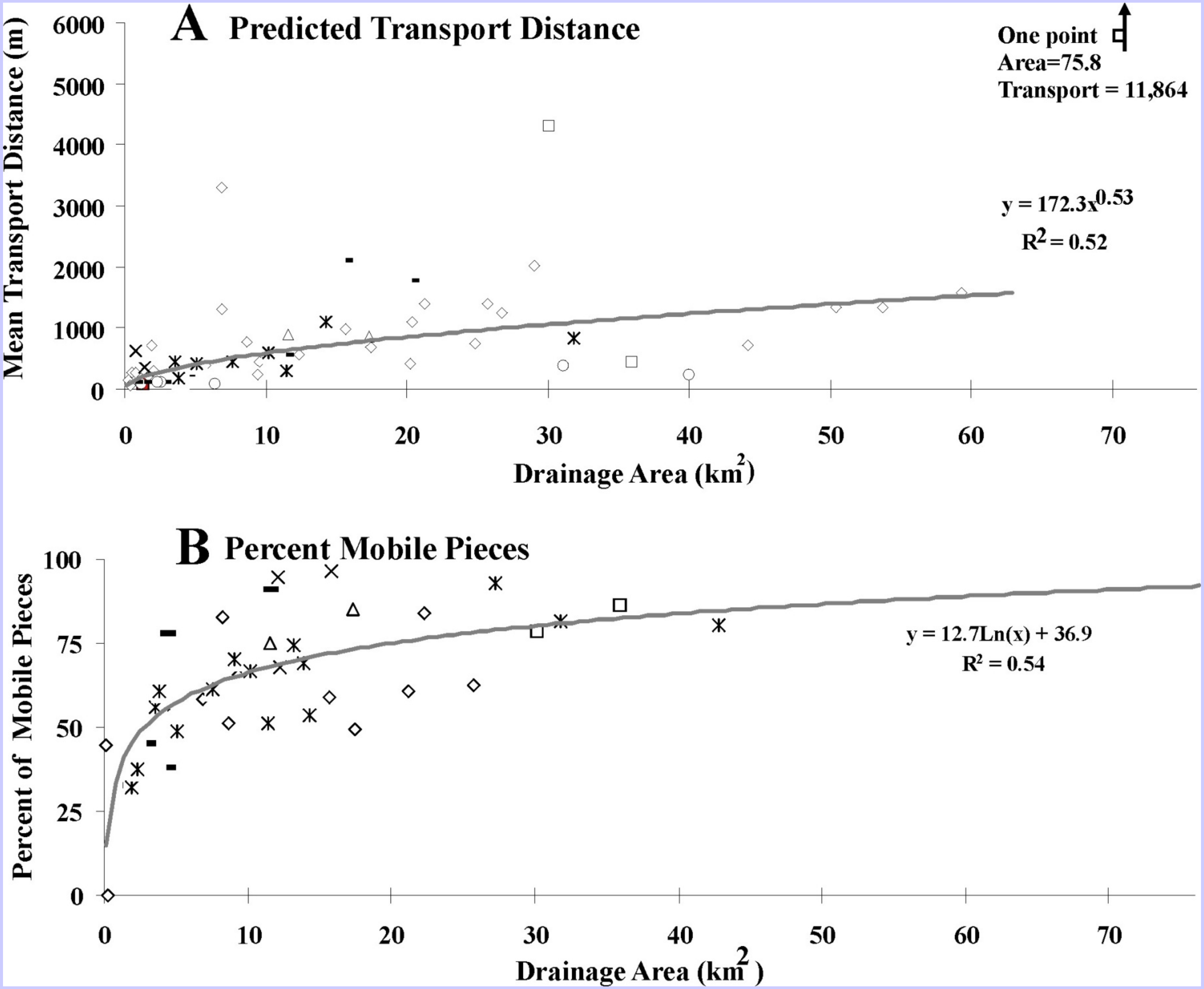
Lj = interjam distance;

Tp = lifetime of wood in streams;

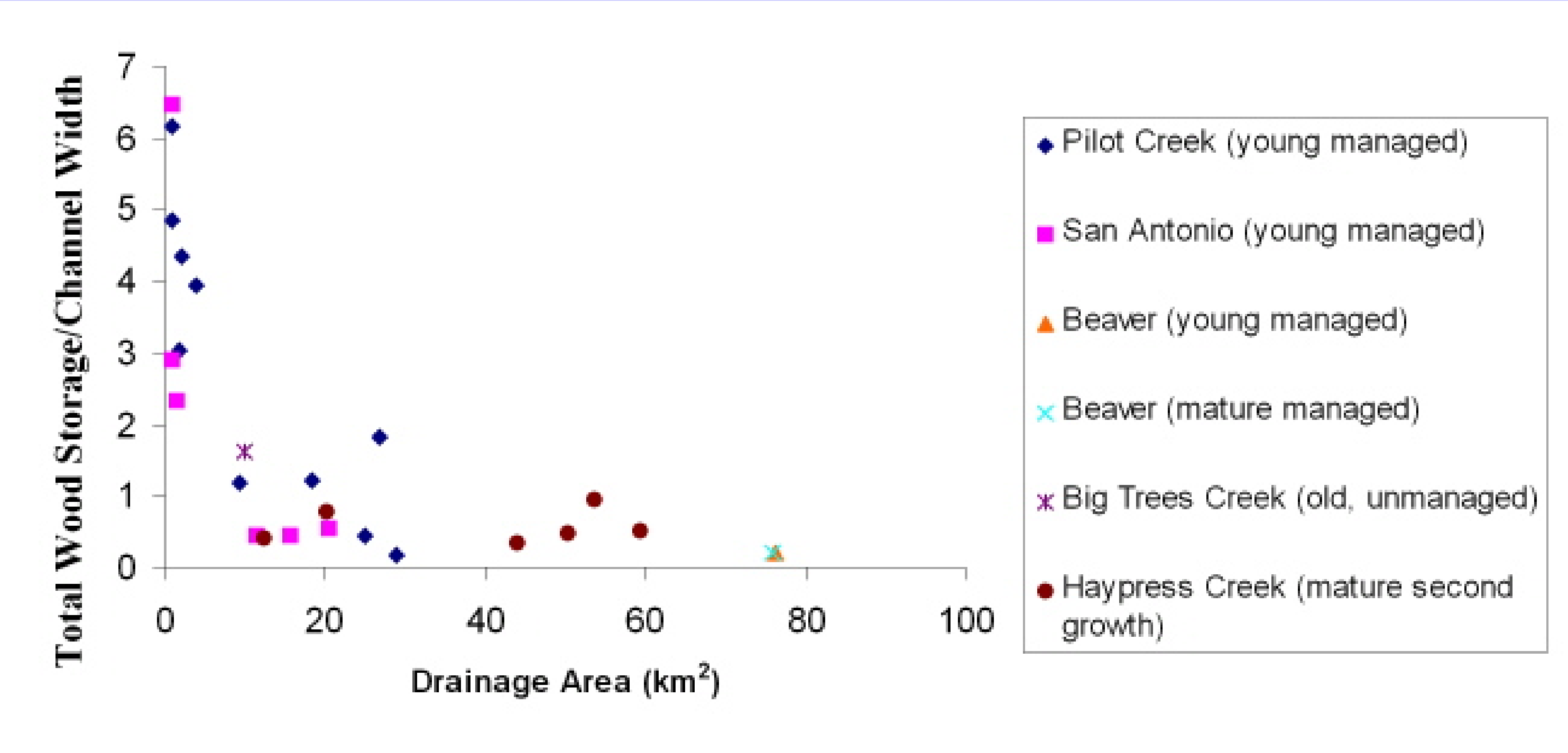
Tj = jam longevity;

β = proportion of channel Spanned by jams


A Distance Between Jams
Coast, unmanaged
Coast, managed
Cascades, unmanged
Cascade, less managed
Cascades, managed
Klamaths, less managed
Sierras, unmanaged
Sierras, less managed
Sierras, managed
Mean Distance Between Jams (m)
y = 36.2x0.3
R2= 0.37
B Percent of Channel Width Blocked by Jams
Percent of Channel Width Blocked by Jam
y = -7.88Ln(x) + 91.8
R2= 0.45
C Jam Age
Mean Jam Age (years)
y = 30.9x -0.20
R2= 0.31
Drainage Area (km2)

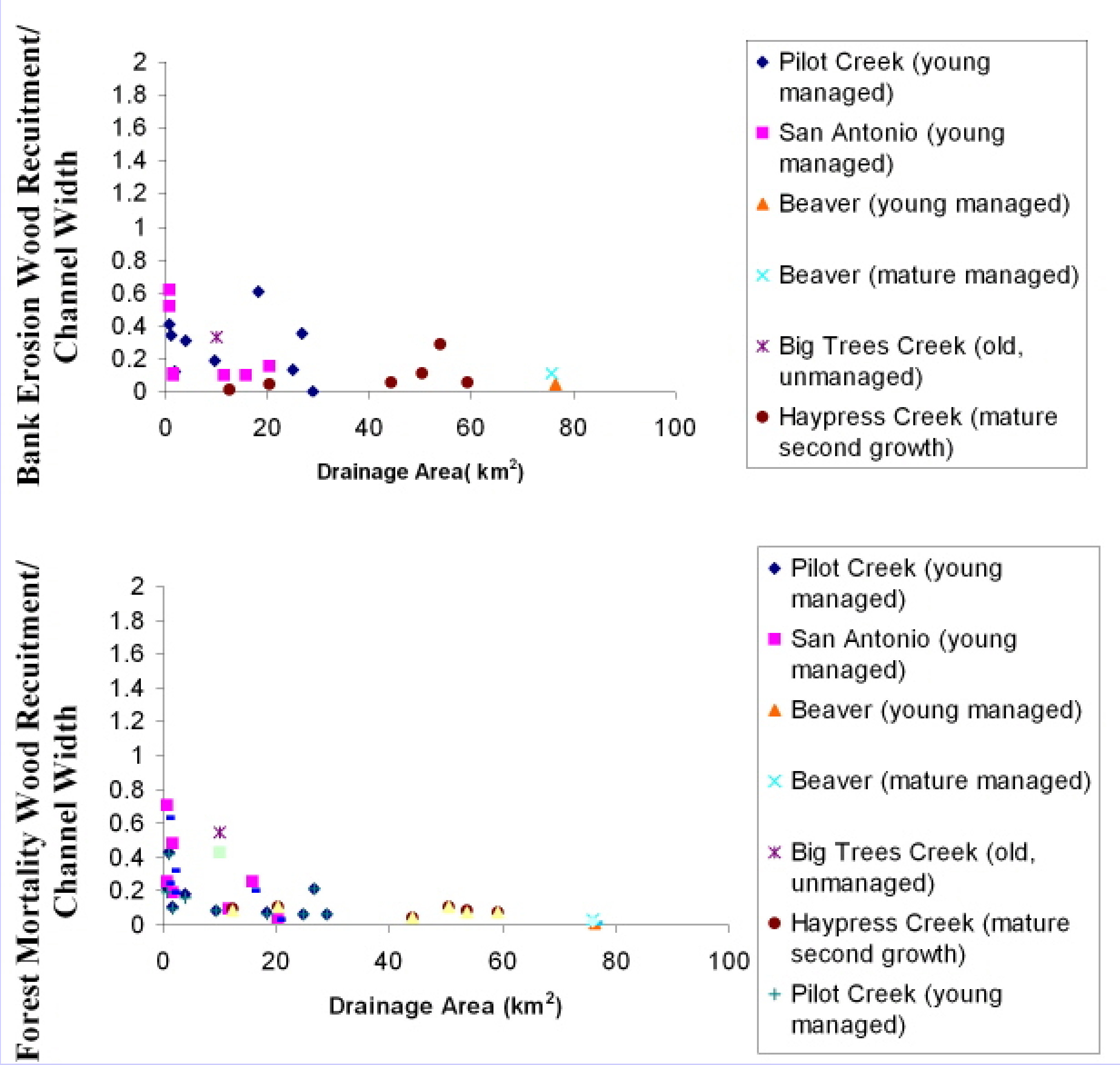

A Predicted Transport Distance
Mean Transport Distance (m)
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
Drainage Area (km2)
One point
Area=75.8
Transport = 11,864
y = 172.3x0.53
R2 = 0.52
B Percent Mobile Pieces
Percent of Mobile Pieces
100
75
50
25
0
0
10
20
30
40
50
60
70
Drainage Area (km2)
y = 12.7Ln(x) + 36.9
R2 = 0.54

Is There a Sampling Bias? Are we more likely to detect wood from bank erosion compared to mortality?



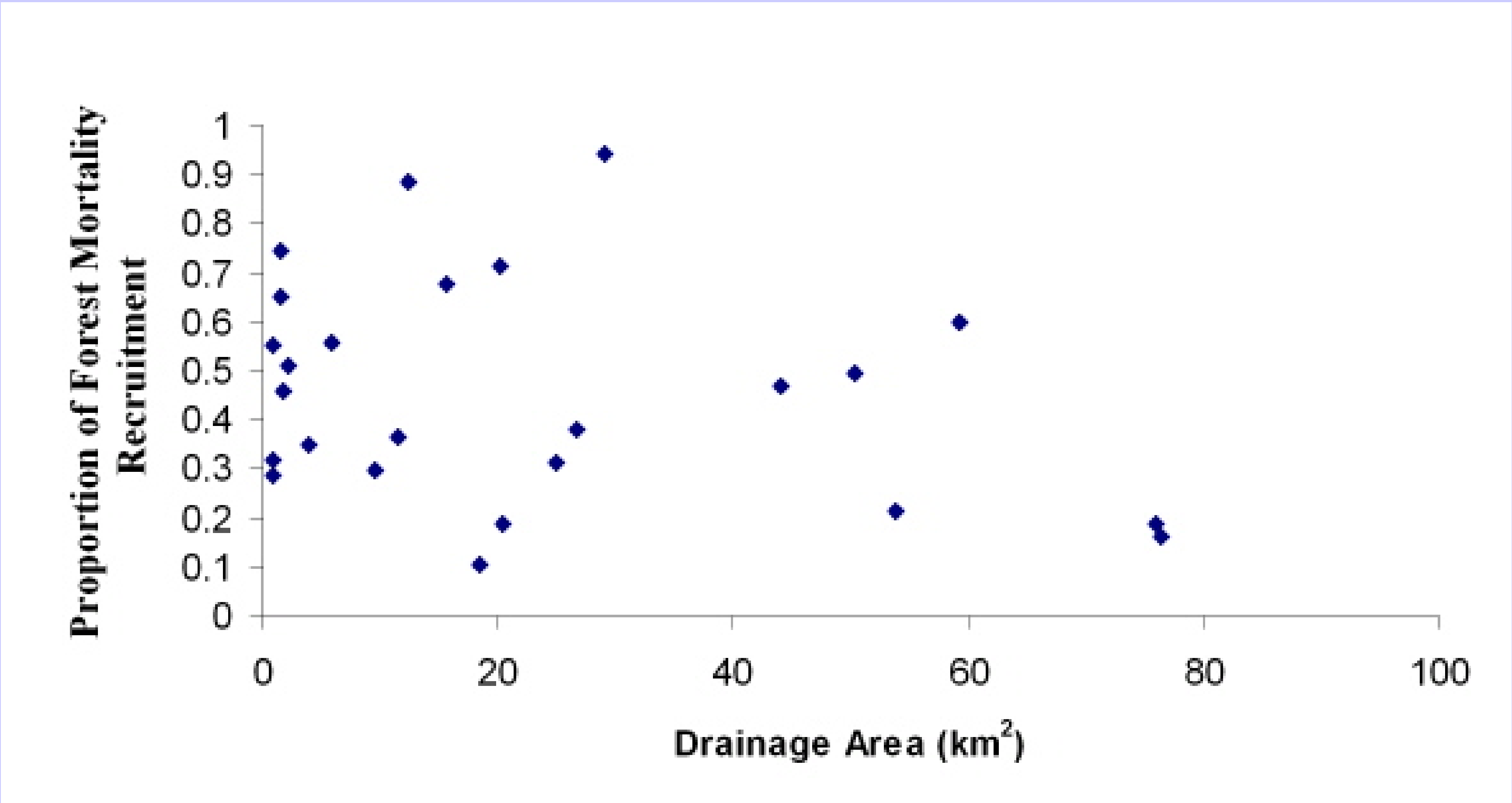
There is a loss of wood storage downstream due to fluvial transport

Is There a Sampling Bias?



Bank erosion and mortality wood loss about the same

Is There a Sampling Bias?



Data from approximately 100 km of stream suggest no significant sampling bias in the methods used.

Comparison to other studies in California
-see paper

Location	This Study	Wooster and Hilton 2004	Lisle 2002
Coast Unmanaged	280-1150 m^3/ha (ave. 830, median 1500)	455-723 m^3/ha (ave. 589)	200-4600 m^3/ha (median 1000)
Coast Managed	300-1100 m^3/ha (ave. 1000)	139-758 m^3/ha (ave. 251)	--
Klamaths Less Managed	0-724 m^3/ha (median 255)	--	18-1600 m^3/ha (median 250)
Cascades mature and old forest	1-125 m^3/ha (median 50)	--	36-100 m^3/ha (median 300)
Sierras old forest	0-485 m^3/ha (median 180)		2.2-100 m^3/ha (median 30)

Conclusions:

-Huge variability at the reach and valley segment scale (factor of 30), mostly driven by process

-Largest wood storage coast – decreasing to Sierras

-No province scale effect on variation in recruitment processes (exception – more landslide wood in coast)

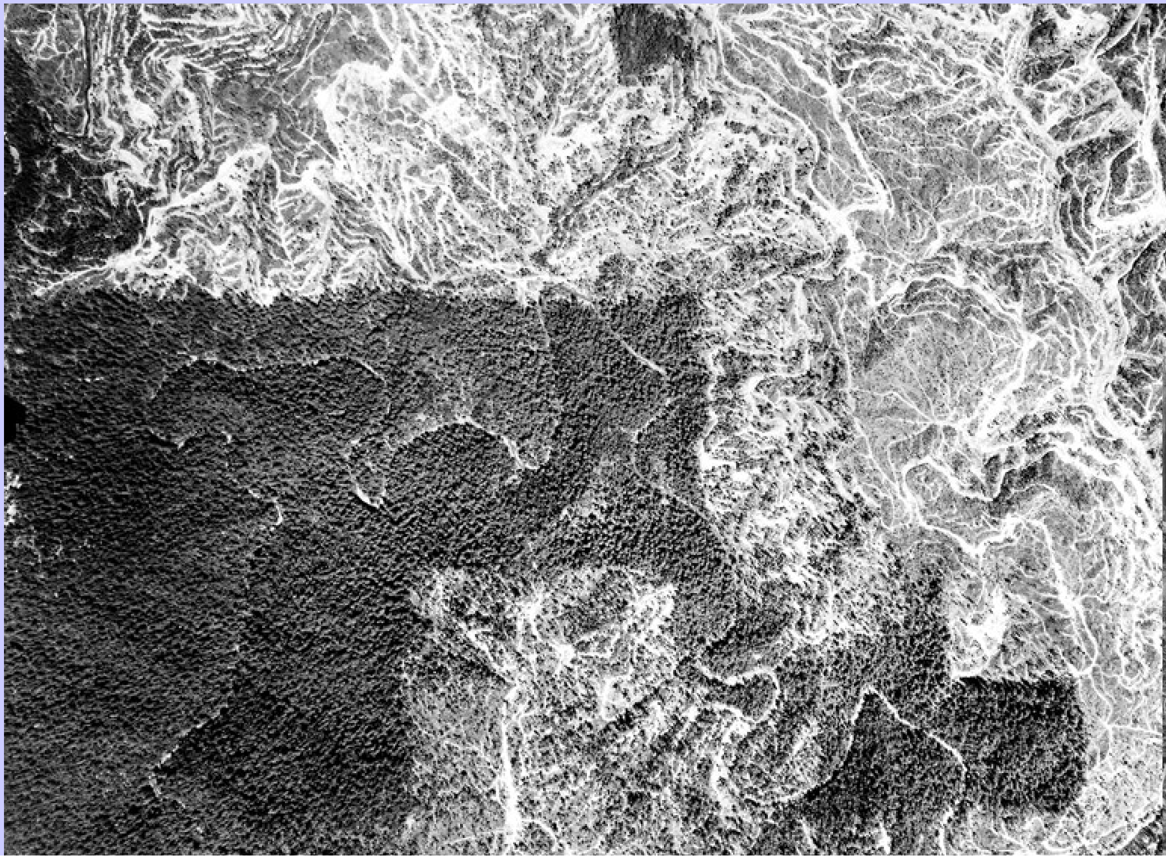
-Source distance of wood dependent on process and on tree age (ht)

-Key pieces that form pools, ave. = 0.7 m

-Greater wood formed pools in coastal less in Klamaths/Sierras

-Implications for riparian zone management?

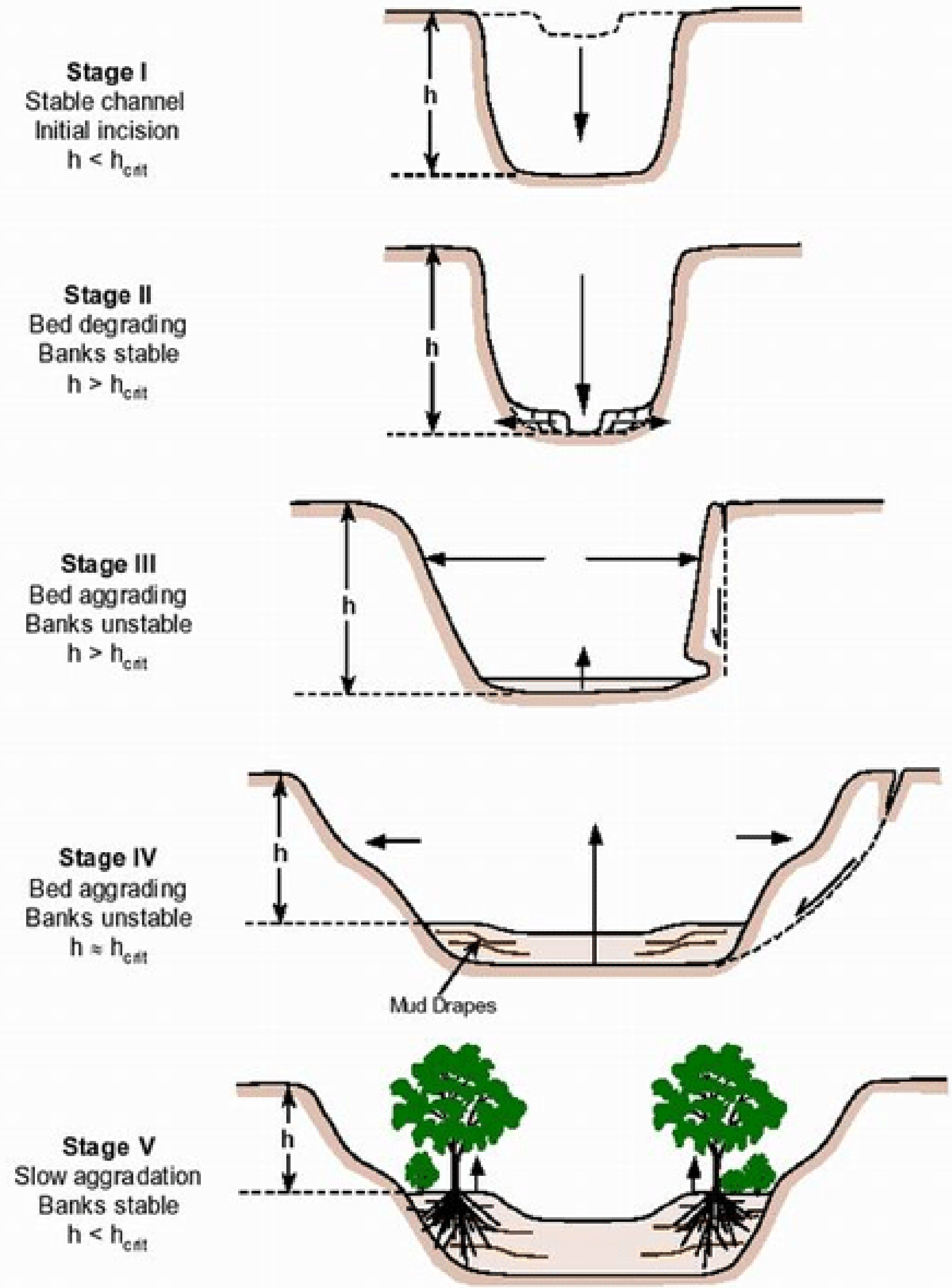
Tractor Legacy Logging and Channel Incision: Will the Elephant in the Watershed Please Stand Up



Low Order Stream Filling with Slash and Fill for Skid Trails and Landings

Typical Response to Disturbance:

Incised Channel Evolution Model

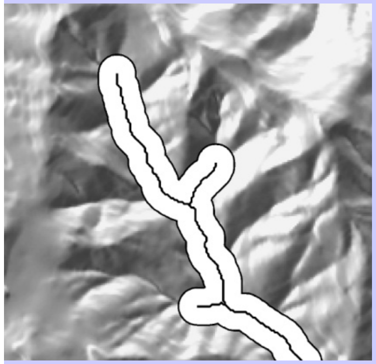


The Low Order Streams Today

Low Order Streams Comprise ~80% of the Stream Network

Implications for Sediment Q, TMDLs, Fisheries, Restoration?

- TMDLs don’t acknowledge this massive source of sediment, strange?
- Contemporary research focuses on incision from current logging practices (e.g. Reid et al. 2010)
- No research at all on the amount of sediment currently contributed from legacy tractor logging, nor it’s trajectory?
- **Why?**



Is rule based uniformity in riparian management the best ecological approach in spatially heterogeneous watersheds and in altered and dynamic environments, particularly in the context of climate change and endangered species?

Or, is it simply a dated policy that is easy to implement and to monitor compliance?

(1) What is the definition of a reserve, in the ecological sense?

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(2) Has the trend (in the last 20-30 yrs) in federal and state forest practice rules been toward creating riparian “reserves”, that is, no activity for perpetuity?

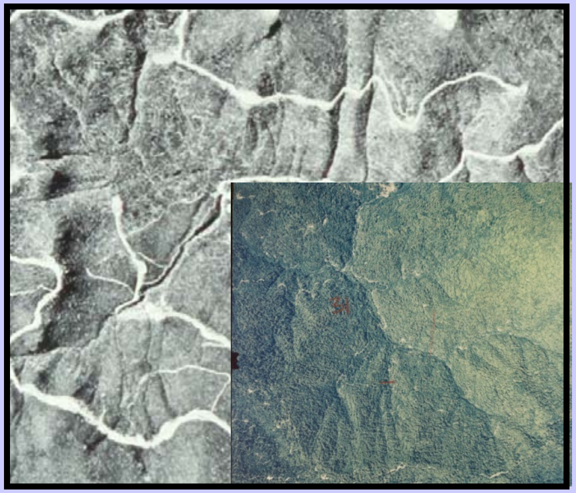
(1) What is the definition of a reserve, in the ecological sense?

(2) Has the trend (in the last 20-30 yrs) in federal and state forest practice rules been toward creating riparian “reserves”, that is, no activity for perpetuity?

(3) Has the vast majority of riparian forests on federal, state and private land has been modified?
-past logging
-fire suppression (higher fuels)
-grazing
-climate change (insects, disease, fire)?

Riparian protection reserves are not being applied to pristine systems

Logging history – young, dense stands



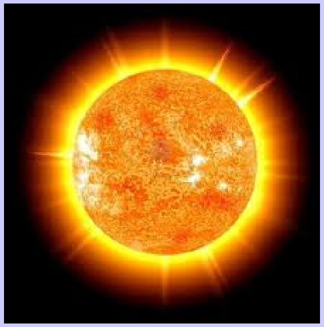
Fire suppression - fuels

Log drives, splash dams

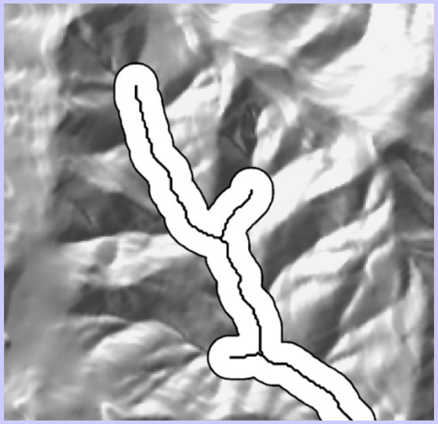
Stream cleaning

Western Pine Bark Beetle

Climate change



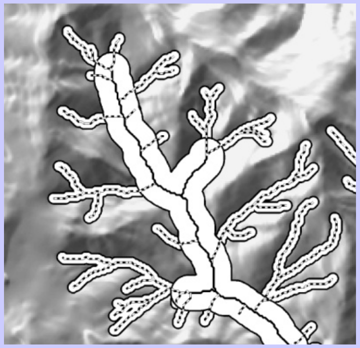
Uniform, prescriptive riparian buffers (reserves) ‘lock in’ altered riparian-channel environments for decades to a century or more



Consequences:

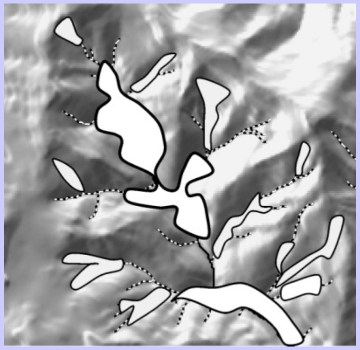
-age/species uniformity (reduced variation)
-dense forests with slow growth
-high fuel loads (high fire risk)
-low in-stream wood accumulation
-poor fish habitat conditions
-poor mammal and avian habitat conditions

What are strategic/restorative options?



Uniform riparian reserves, limited (or no) options

❖General rules: fish/non fish, stream size



Spatially explicit and variable, many options

❖ Strategically design buffers based on condition and process

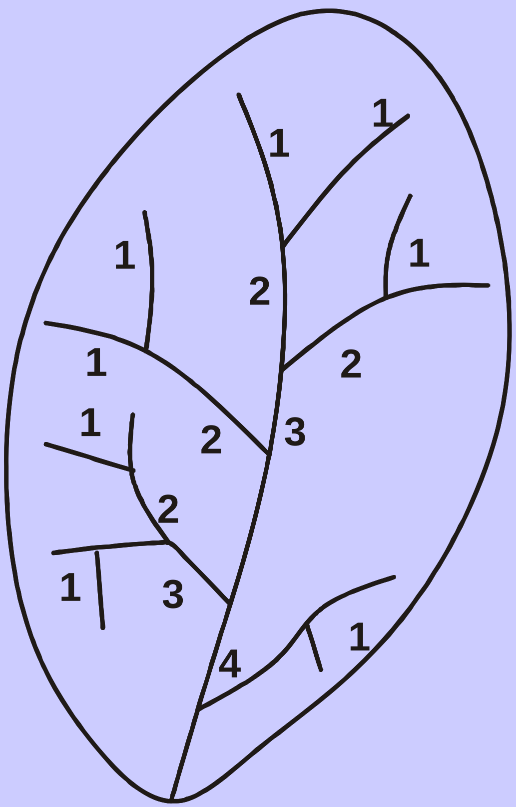
- ➢habitat quality and distribution
- ➢thermal, wood recruitment, food, erosion
- ➢other animal requirements (migration/connectivity)
- ➢disturbance principles
- ➢road impacts

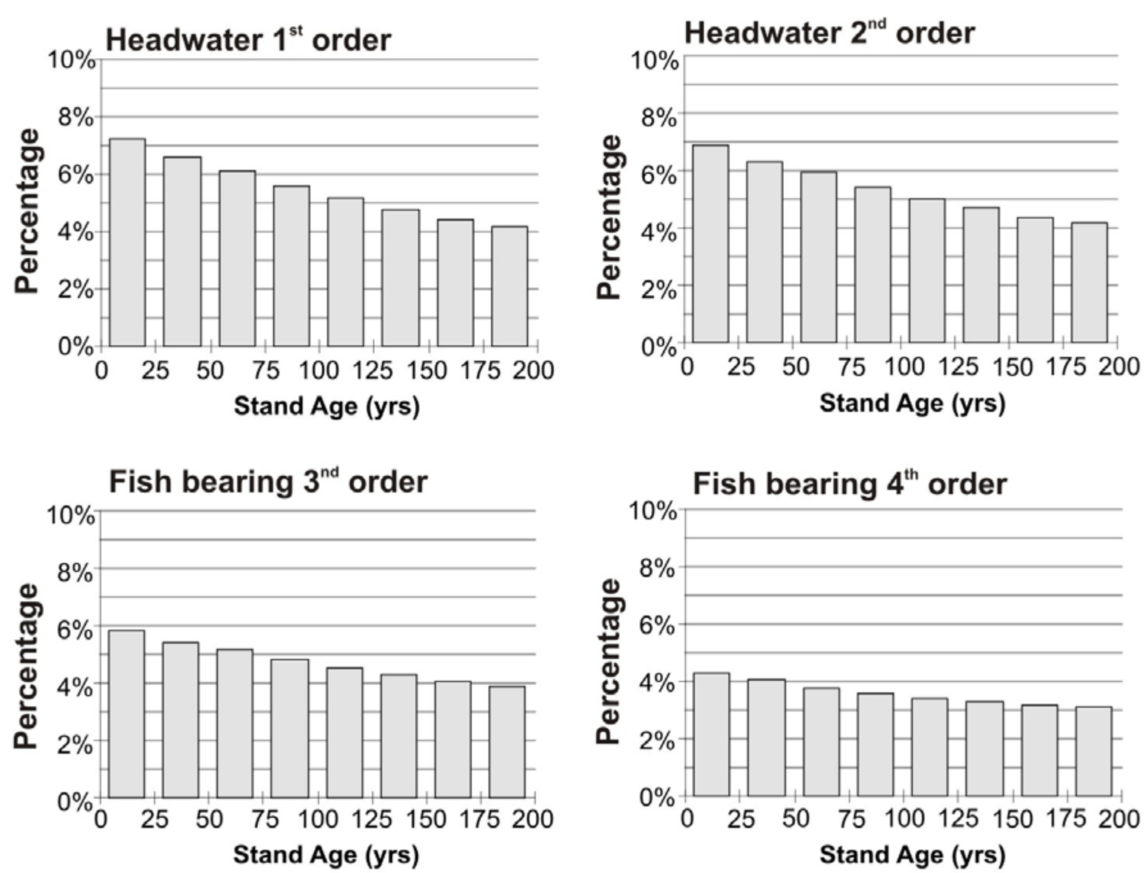
❖Interventionist forest/stream restoration

- ➢thin dense 2nd growth
- ➢create fire breaks
- ➢create light openings (food production)
- ➢convert tree species
- ➢improve in-stream wood, substrate, floodplains

For riparian zone management, what is the appropriate ecological target?

Southwest WA Landscape
Fire frequency (basin) = 300 yrs
Ridge/south aspect = 175 yrs
Lowland valley = 400 yrs





Evolution in science, technology and understanding should lead to evolution in regulatory policy