Effects of Alluvial and Debris Flow Fans on Channel Morphology in Idaho, Washington, and Oregon

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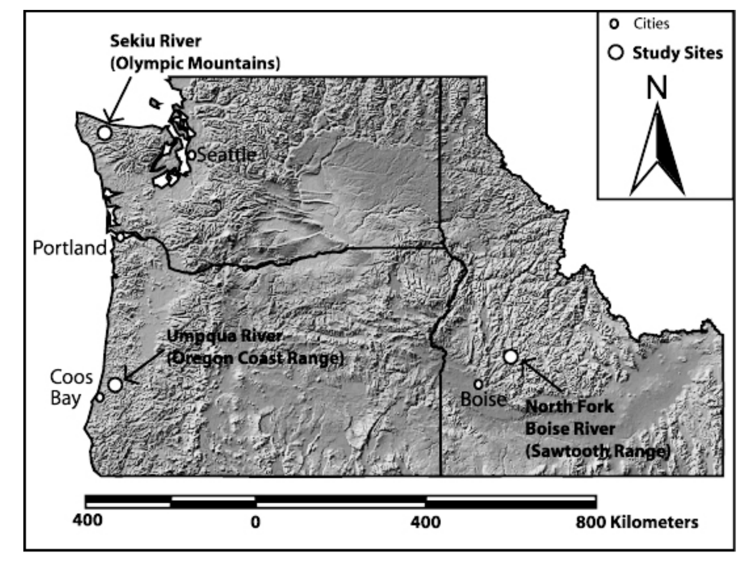
Introduction

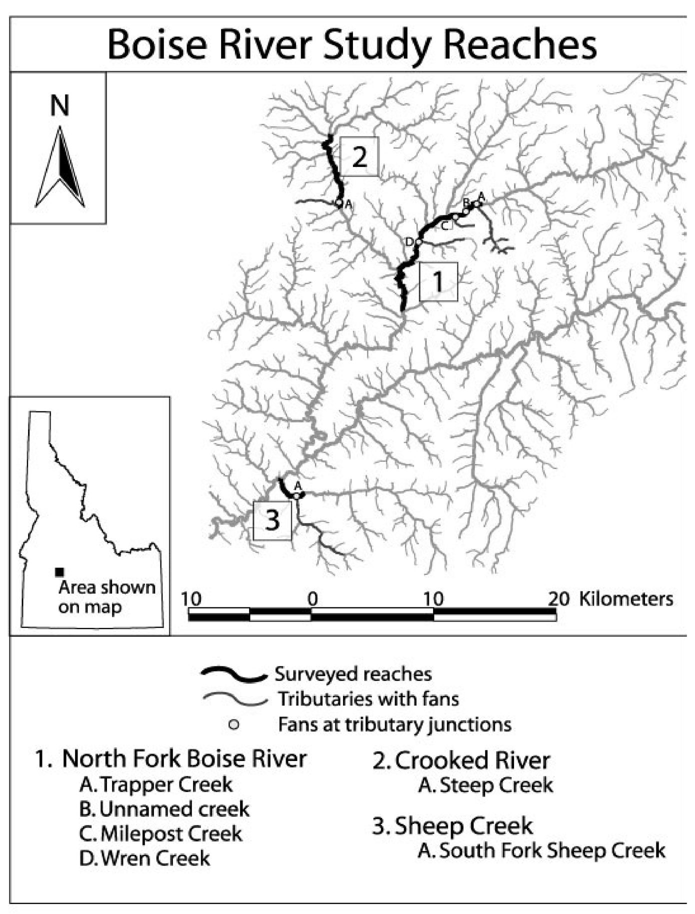
Formation of debris flow and alluvial fans at tributary confluences from episodic erosion associated with large storms and fires ("extreme events") are often viewed negatively over short time spans (years). However, when viewed over long periods of time (decades to centuries), fans that form at tributary junctions are often sources of morphological diversity in streams and rivers.

To evaluate effects of tributary fans on the morphology of mainstem channels, we surveyed a total of 44 km of streams in the Sawtooth Mountains of Idaho, Olympic Mountains of Washington, and Central Coast Range of Oregon. Field work generally consisted of continuous channel surveys of gradient, channel width, flood-plain width, valley floor width, substrate sizes, large wood (number of pieces), pools, fan extent, fan age (recent, old), terraces (reoccupied, old), side channels, and bars. See the journal articles for more details on methods (Benda et al. 2003a; Benda et al. 2003b).



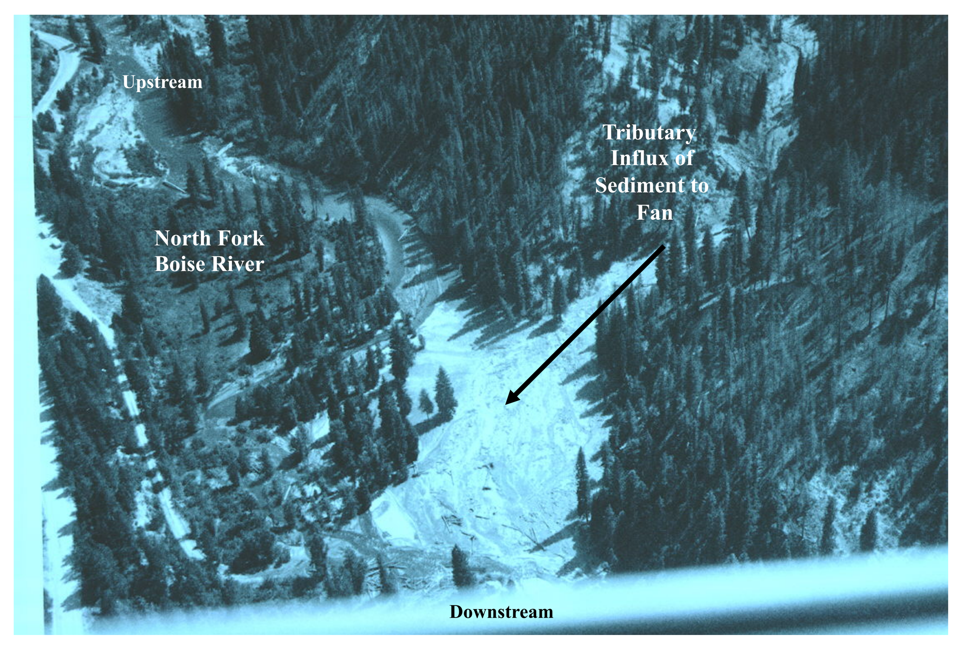
Idaho - Alluvial Fans

Sawtooth Mountains, Boise River and Tributaries

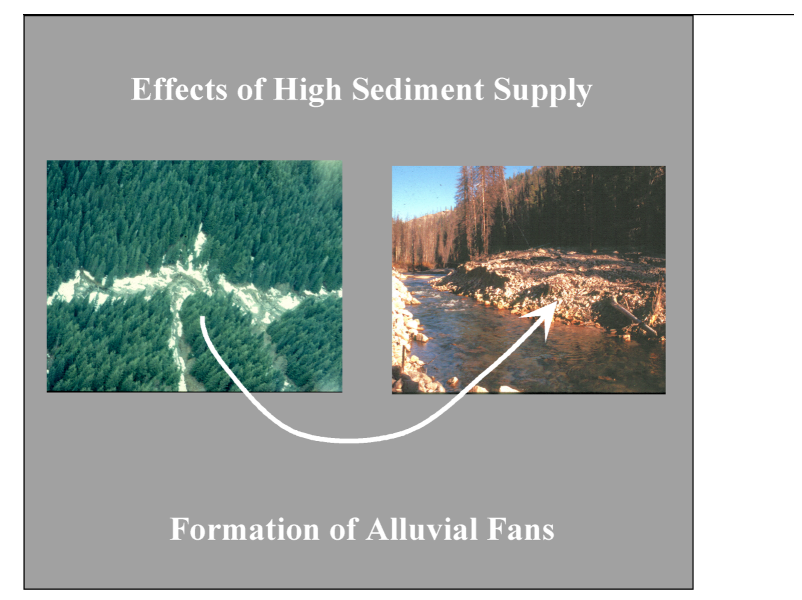


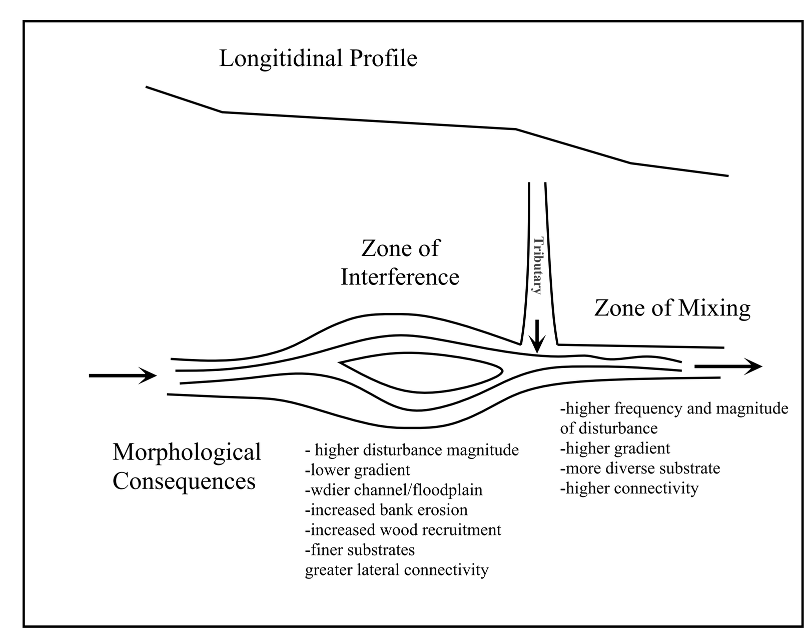
Twenty-seven km of channel were surveyed to document effects of punctuated erosion on channel morphology following a stand replacing fire (1995 Rabbit Fire) and subsequent summer thunderstorm (1996).

Stream Name	Reach Length (km)	Drainage Area (km^2)	Mean Gradient (%)	Mean Width (m)	Dominant Substrate	Dominant Channel Type
1. North Fork Boise River	16	220	1.4	32	Cobble / Gravel	Pool-Riffle
2. Crooked River	8	140	1.6	16	Gravel / Cobble	Pool-Riffle
3. Sheep Creek	3	107	3.1	9	Cobble / Boulder	Step Pool

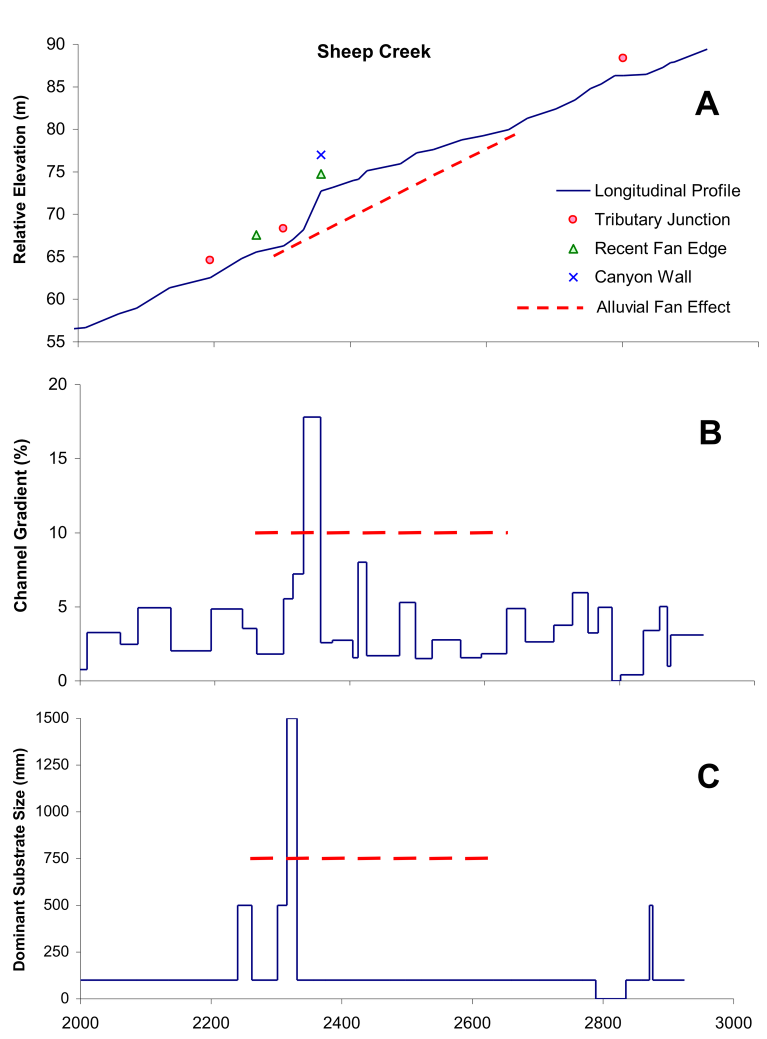


A number of alluvial fans were rejuvenated, often impinging on the receiving channel (above) and included massive amounts of wood (below) that was later removed to protect bridges.

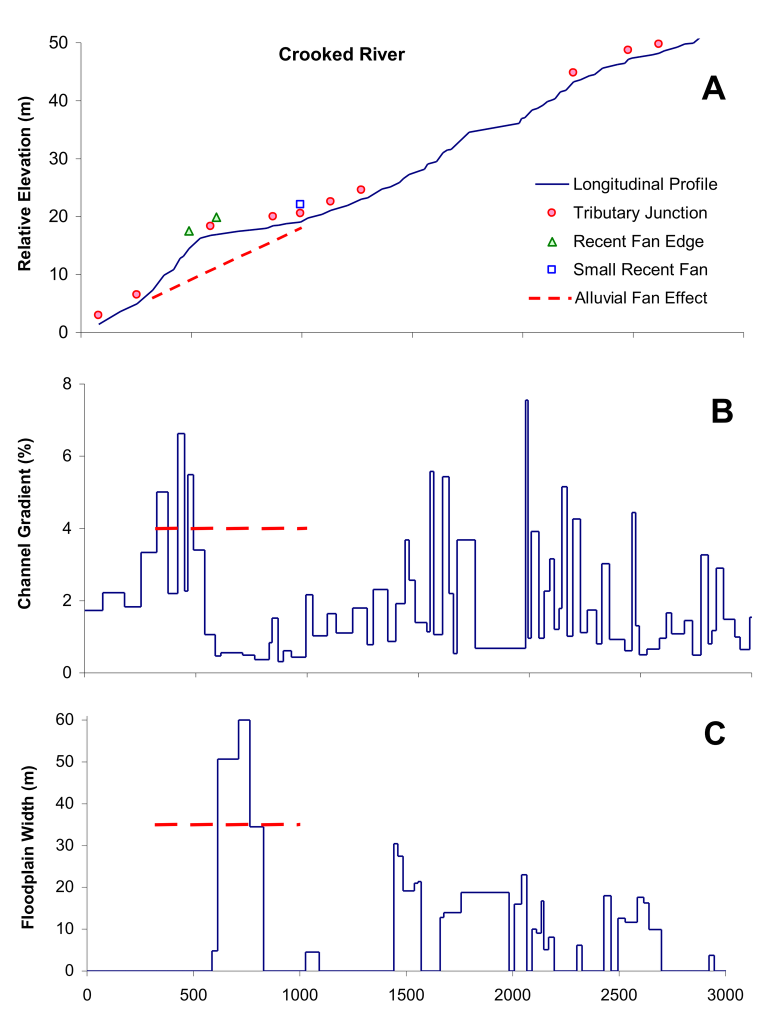




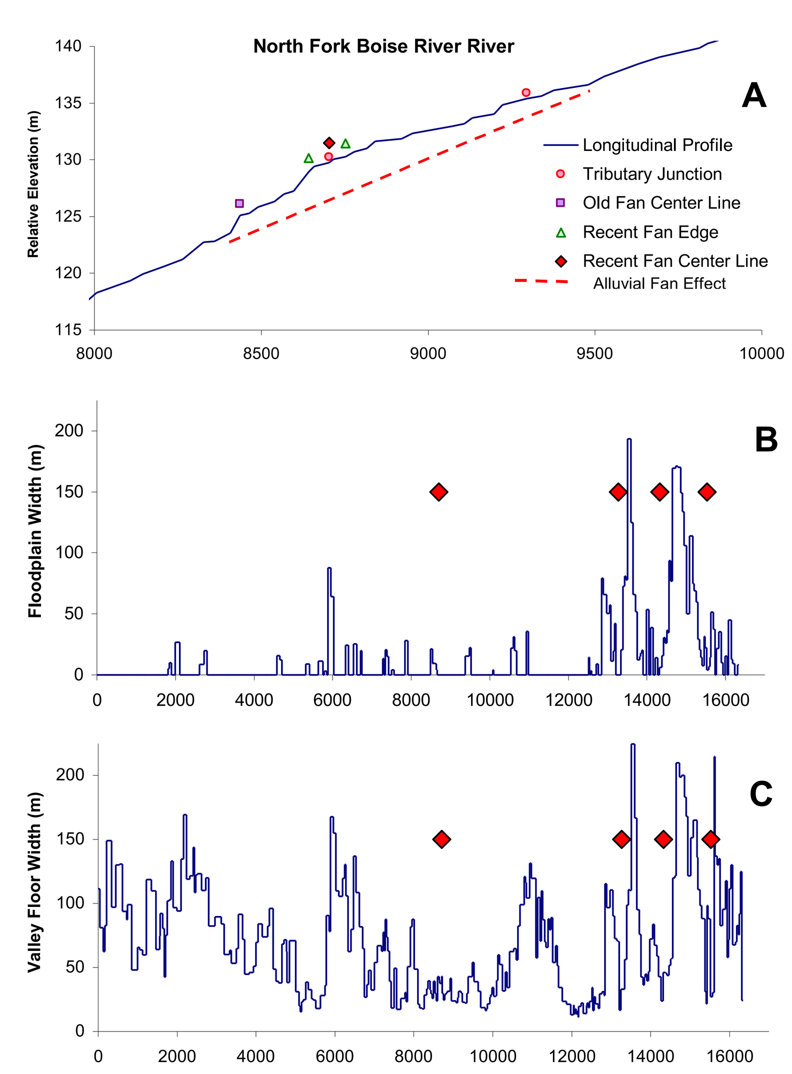
Generalized sketch showing up and downstream effects of tributary alluvial fans on receiving channel morphology.



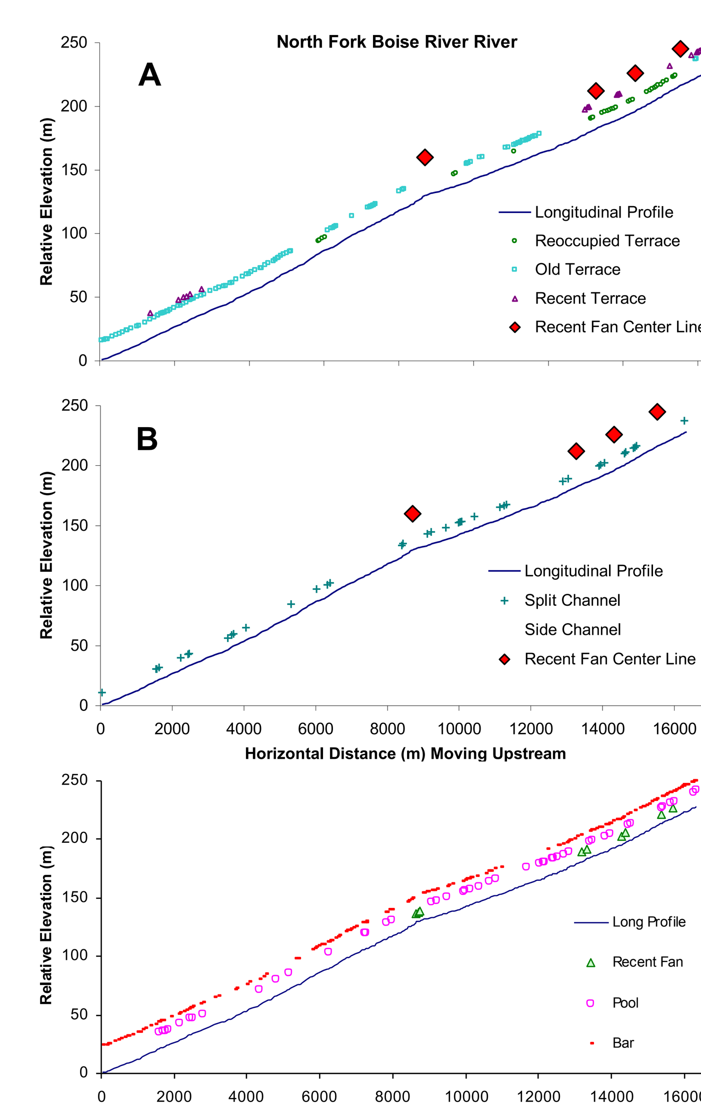
Sheep Creek. (A) Long profile showing the nickpoint created by a rejuvenated alluvial fan, resulting in (B) shallow gradients upstream of the fan and steep gradients downstream of the fan, and (C) boulder deposits on the downstream edge of the fan causing finer material to deposit upstream of the fan.



Crooked River. (A) Long profile showing the nickpoint created by a rejuvenated alluvial fan, resulting in (B) shallow gradients upstream of the fan and steep gradients downstream of the fan, and (C) wide flood plains.



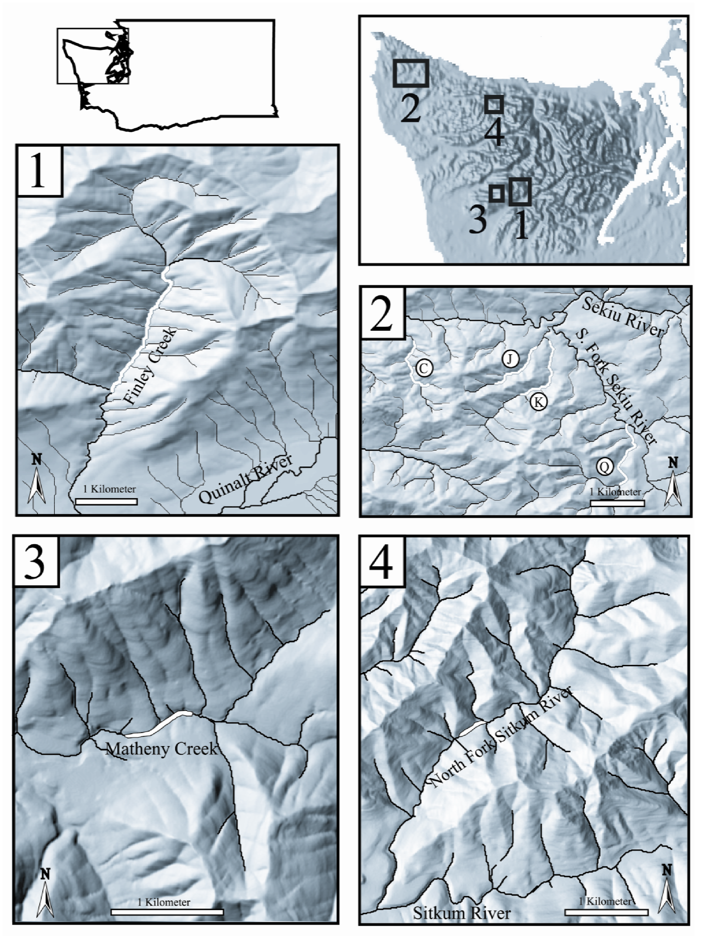
North Fork Boise River. (A) Long profile showing the nickpoint created by a rejuvenated alluvial fan, resulting in (B) widest floodplains in the vicinity of three of the recent fans. (C) A narrow valley floor did not allow flood plain widening at one rejuvenated fan (Wren Creek fan at ~9000 m).



North Fork Boise River. (A) "Reoccupied terraces" (recently covered with overbank flows and fine sediment), (B) side channels, and (C) deep pools (>1 m) are concentrated in the area of the three recent fans.

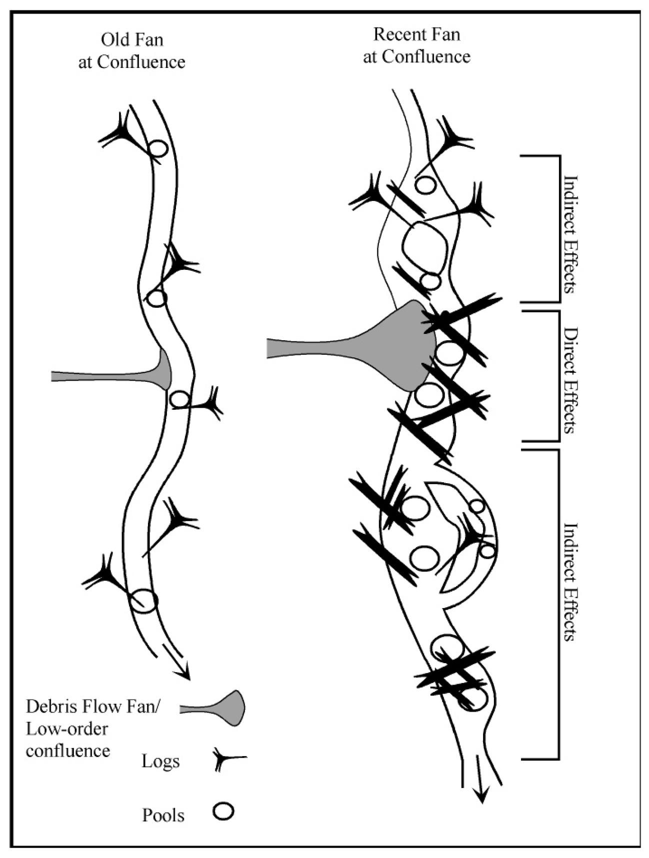
Washington - Debris Flow Fans

Olympic Mountains, Quinault and Sitkum River Tributaries

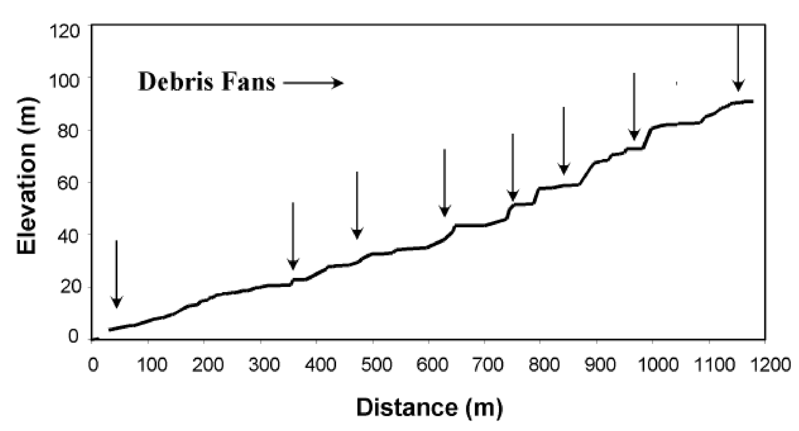


Ten km of channel were surveyed to evaluate the effects of debris flow fan deposits on channel morphology. Many of the debris flows occurred recently (1997).

Site	Forest Condition	Drainage Area (km^2)	Length (km)	Gradient (Map %)	Typical Debris Volume (m^3)
Finley Creek	Unmanaged	16-Aug	3	3 – 7	~500 - 2000
Matheny Creek	Unmanaged/patch logged	4.4	8	3 – 6	3000 – 7000
Sitkum River	Unmanaged/patch logged	11	6	8	~100,000+
Sekiu - C Tributary	Second Growth	1.5 – 2	1.3	3	~1000 - 3000
Sekiu – J Tributary	Second Growth	1 – 1.5	1.2	4	~1000
Sekiu – K Tributary	Second Growth	2.5 – 3.3	0.9	2.5	~1000
Sekiu - Q Tributary	Second Growth	3 – 4.5	2.5	2.5	~1000

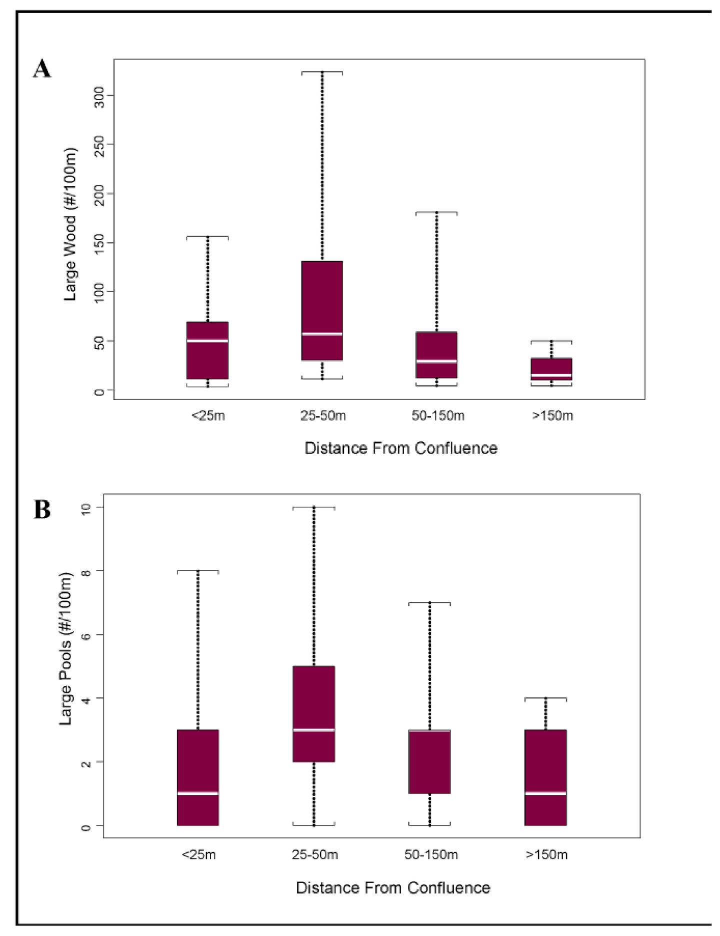


Generalized sketch showing both "direct" and more extensive "indirect" effects of debris flow deposits and fans on channel morphology.

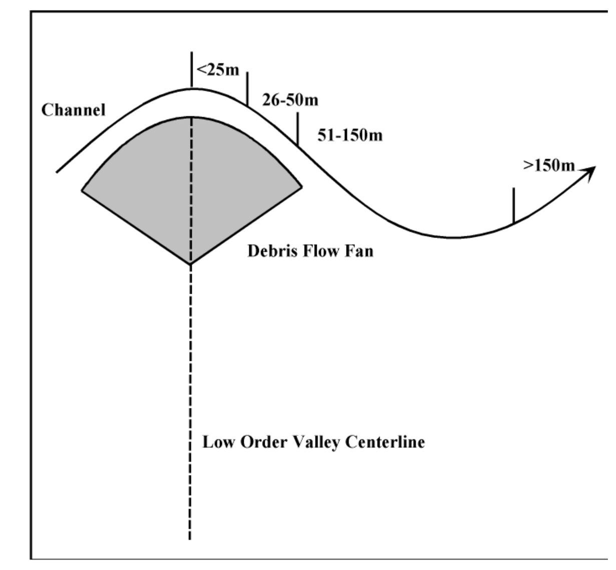


Long profile on J Tributary showing nickpoints created by debris fans.

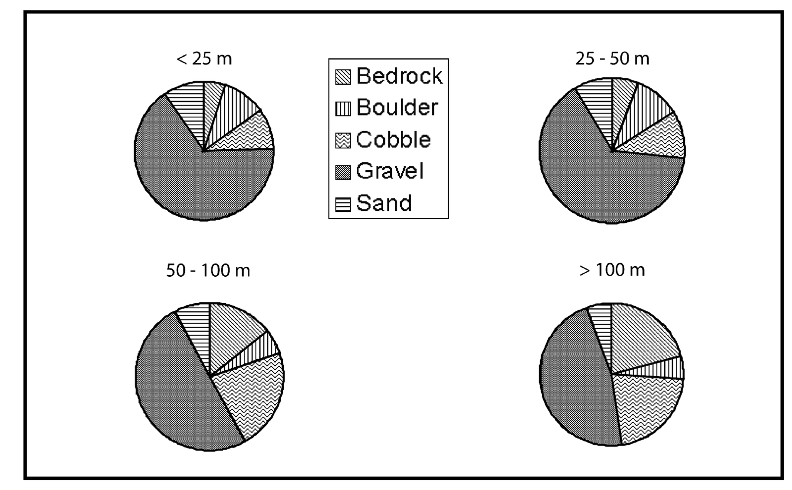
Typical debris flow deposit with large influx of wood



Sekiu Basin Tributaries. Box and whisker plots showing statistically higher (ANOVA, p = 0.01) (A) large wood and (B) pools densities near the debris fans (20-50 m bin) than further away.



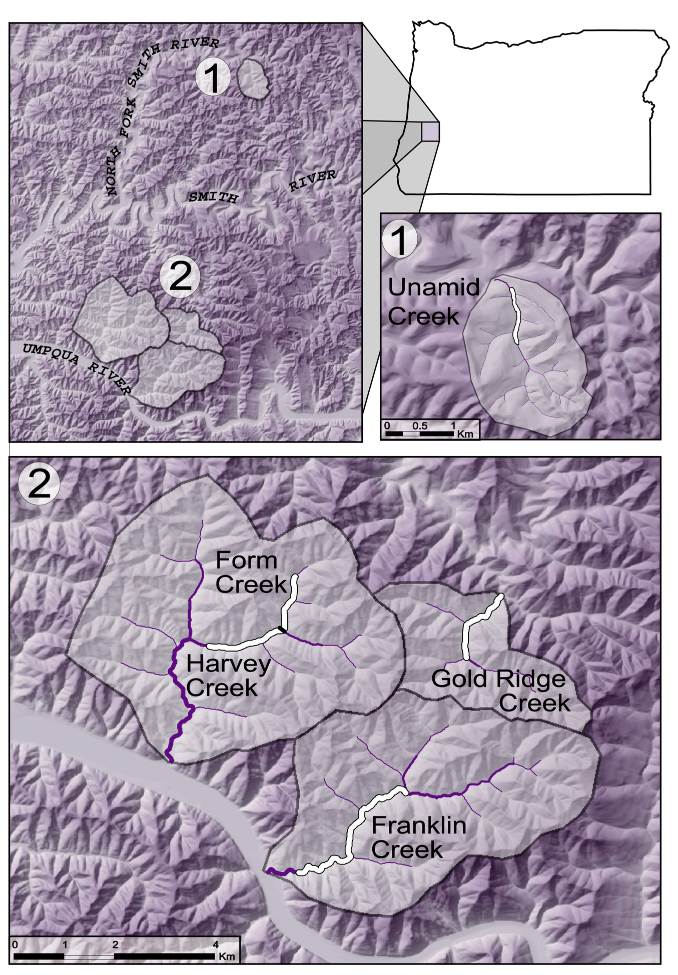
To see how channel parameters change by distance from the debris fan, a statistical (ANOVA) nearest neighbor analysis was performed on grouped distance bins of approximately equal occupancy.



Sekiu Basin Tributaries. Proportion of gravel increases with proximity to debris fans.

Oregon - Debris Flow Fans

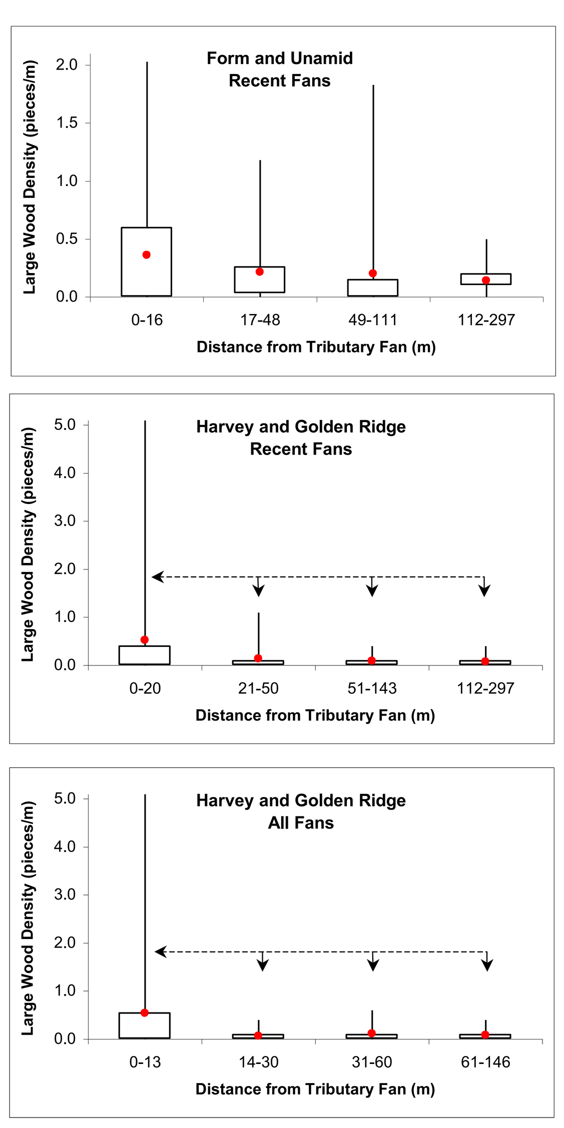
Central Coast Range, Umpqua River Tributaries



Seven km of channel were surveyed to evaluate the effects of both recent and old debris flow fan deposits on channel morphology.

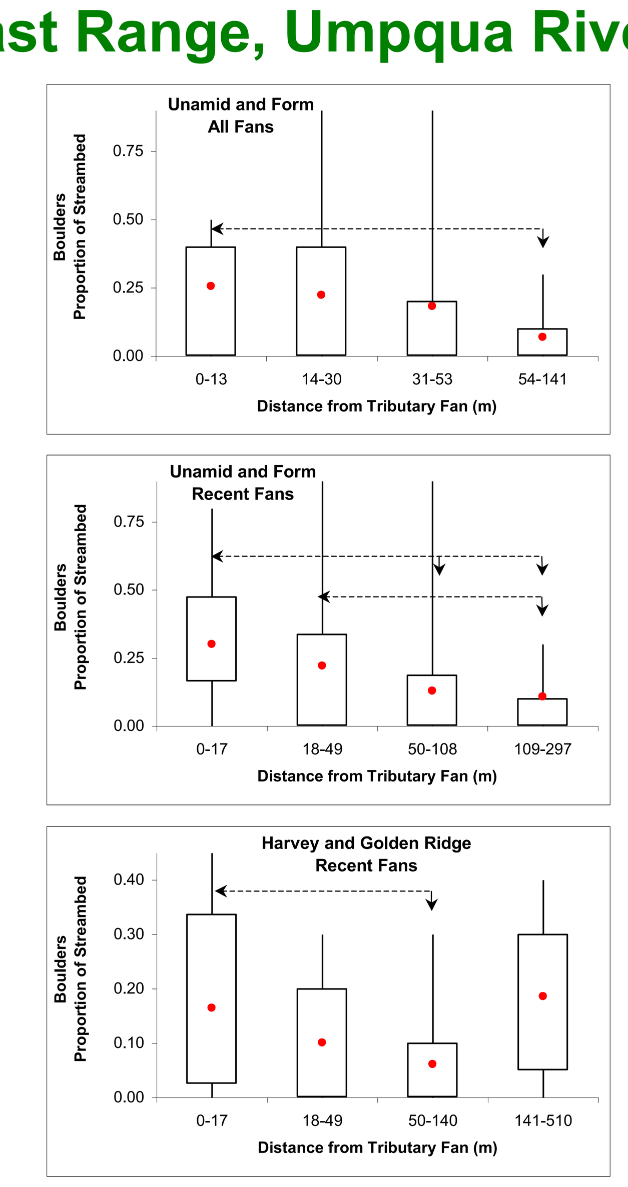
Similar to the Olympic Mountains study, a statistical (ANOVA) nearest neighbor analysis was performed to see how channel parameters change by distance from the debris fan. Basins of similar size were grouped together.

Site	Drainage Area (km^2)
Unamid	3.8
Form	3.1
Harvey	9.6
Golden Ridge	7.0

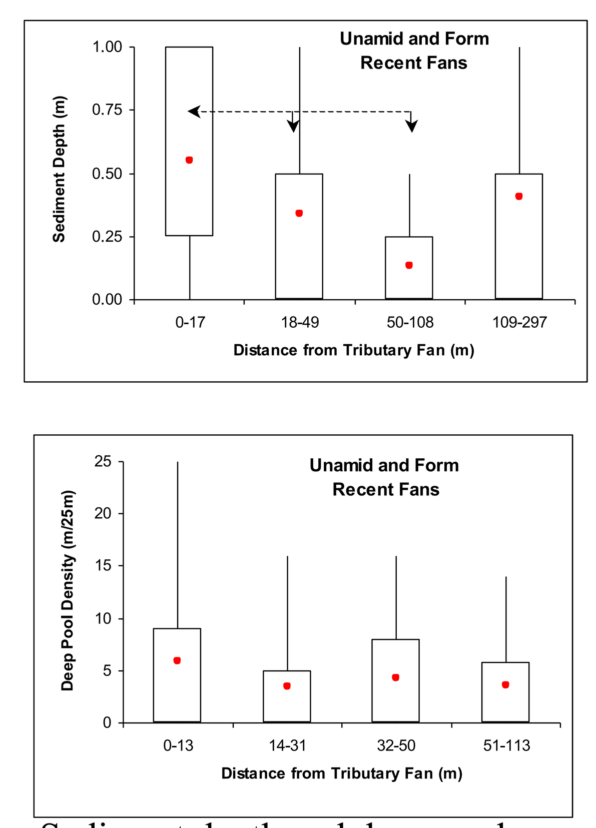


Box and whisker plots showing the density of large wood was higher near debris fans. Arrows indicate statistical differences between bins (ANOVA, p < 0.10).

High wood loading on debris fan.

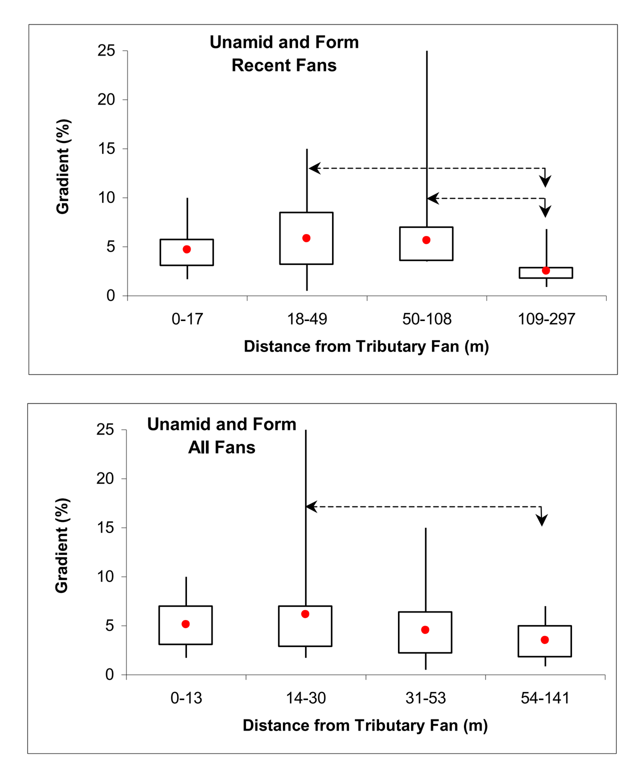


The proportion of boulders was higher near debris fans. Arrows indicate statistical differences between bins (ANOVA, p < 0.10).



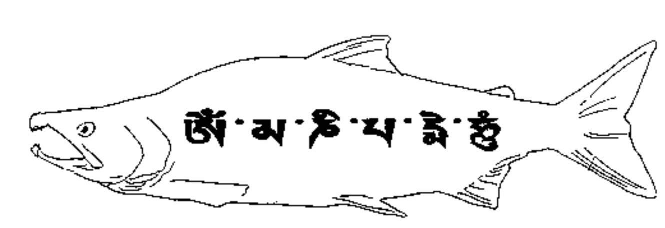
Sediment depth and deep pool density was higher near debris fans.

Boulder deposit and wood input from debris fan.



Gradients were higher near debris fans.

*Debris flow fan effects were not observed in Franklin Creek, where the channel was highly aggraded.



Summary and Conclusions

Rejuvenated alluvial fans resulting from post-fire gully erosion in the Sawtooth Mountains created gradient nick points that increased sediment storage upstream resulting in decreased channel gradients, widened flood plains, side channel construction, and the beginning of terrace formation. Downstream effects included increased channel gradients, often creating rapids.

In the Olympic Mountains, there was statistically significant association between low-order confluences containing debris flow deposits and gravel abundance, wide channels, and numbers of logs and large pools. Moreover, heterogeneity of mainstem channel morphology increased in proximity to low-order confluences prone to debris flows in the Olympic study sites.

In the Oregon Coast Range, density of large wood and boulders in mainstem channels increased with proximity to all debris flow fans at low-order confluences regardless of fan age, while channel gradients and sediment depth in mainstem channels increased with proximity to recent debris fans.

Consequently, alluvial and debris flow fans can be significant agents of heterogeneity in riverine habitats, similar to other sources of major gradient nick points on mainstem channels (e.g. bedrock, rock falls, canyon constrictions, channel bends, etc.).

However, not all channels are prone to tributary fan effects. Steep and confined mountain channels with high stream power may quickly transport deposits from debris flow and alluvial fans, leaving no morphological effects. Also, where channels are highly aggraded, fan effects may not be apparent (e.g. Franklin Creek).

Overall, these field studies provide a physical basis for recent observations of increased habitat use near tributary junctions (e.g. salmon spawning density [e.g. Martin et al. 2003], aquatic invertebrate density [e.g. Rice et al. 2001) and underpin emerging theory on the interaction between river networks and disturbance in creating and maintaining a variety of habitat in aquatic and riparian ecosystems (Benda et al in press (a,b)).

References

Download most of these papers at: http://leebenda.siskiyou.net/publications.html

Benda, L., D. Miller, P. Bigelow, and K. Andras. 2003a. Effects of post-wildfire erosion on channel environments, Boise River, Idaho. Journal of Forest Ecology and Management 178: 105-119.

Benda, L., C. Veldhuisen, J. Black. 2003b. Debris Flows as agents of morphological heterogeneity at low order confluences, Olympics, Washington. Geological Society of America Bulletin 115 (9):1110-1121.

U.S. Forest Service. 2002. Landscape Dynamics and Forest Management: Educational CD-ROM. General Technical Report, RMRS-GTR-101CD, USDA, Rocky Mountain Research Station; screenplay by Benda, L. and Miller, D. (order at www.fs.fed.us/rm or email rschneider@fs.fed.us)

Benda, L., Poff, L, Miller, D., Reeves, G., Dunne, T., Pess, G., and Pollock, M. in press a. Network disturbance hypothesis: how river networks interact with stochastic processes to structure riverine habitats. BioScience (soon available at http://leebenda.siskiyou.net/publications.html)

Benda, L., Andras, K., Miller, D., and Bigelow, P. in press b. Confluence effects in rivers: role of basin scale, network geometry, and disturbance regimes. Water Resources Research (soon available at http://leebenda.siskiyou.net/publications.html)

Martin, D., Benda, L., Lucchetti, G., and Fuerstenberg, R. 2003. The influence of channel geomorphology and disturbance processes on the spatial structure of chinook salmon populations in rivers. Geological Society of America 2003 Seattle Annual Meeting, paper no. 129-13.

Rice, S. P., M. T. Greenwood, et al. 2001. Tributaries, sediment sources, and the longitudinal organization of macroinvertebrate fauna along river systems. Canadian Journal of Fisheries and Aquatic Sciences 58: 824-840.