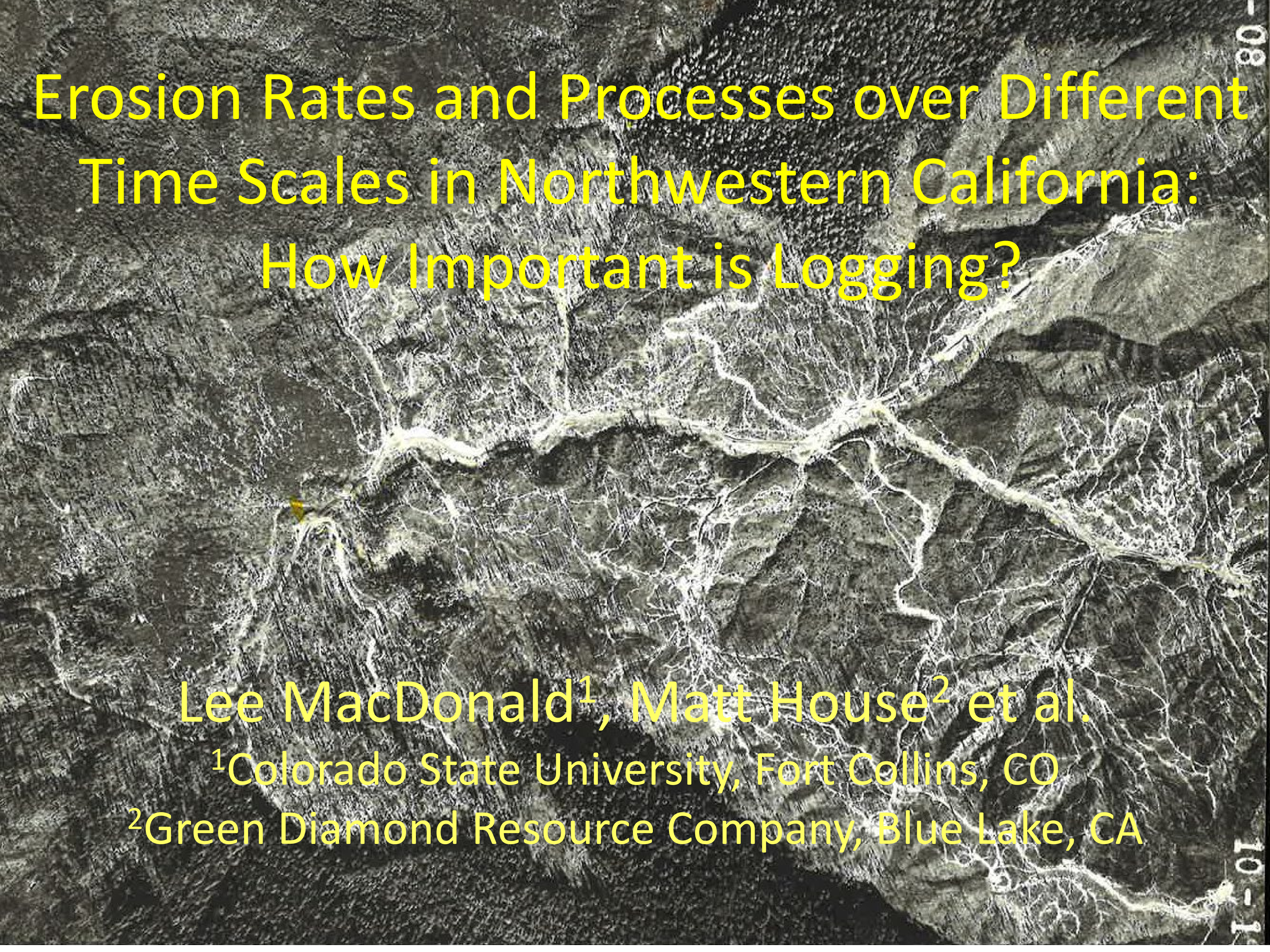
Erosion Rates and Processes over Different Time Scales in Northwestern California: How Important is Logging?



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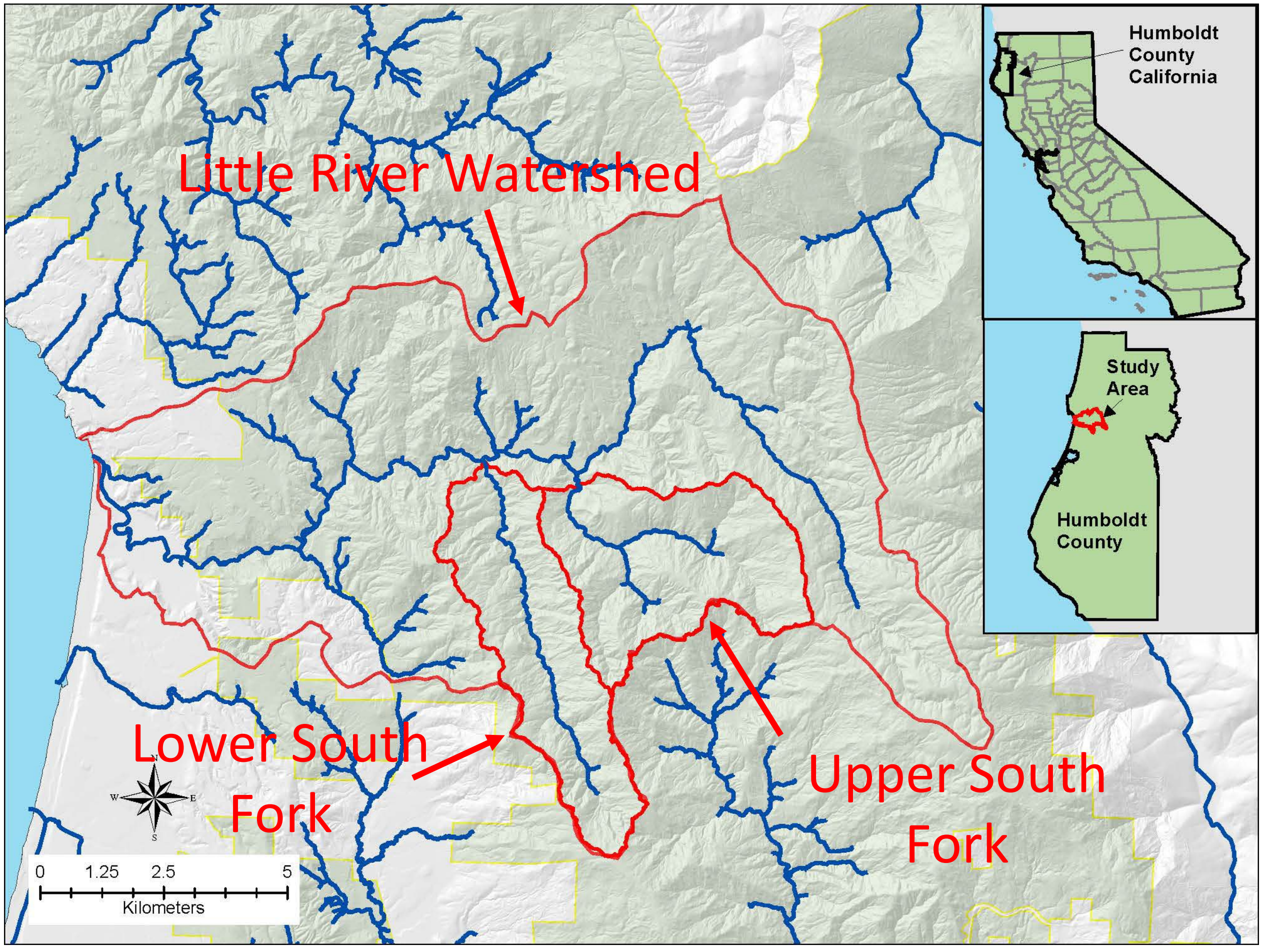
Objectives

1. Estimate/measure the effect of past and current forest management activities on erosion rates, sediment yields, and fisheries;
2. Quantify the different sources of erosion (e.g., harvest units, roads, landslides);
3. Put legacy and recent erosion rates into a longer term context;
4. Use the results to inform management practices and forest practice regulations, with implications also for water quality and sediment TMDLs;
5. Submit the results to a peer-reviewed journal.

Study focused on two tributaries of the Little River watershed in northwestern CA



Primarily coast redwood with some Douglas-fir

Entirely owned by Green Diamond Resource Company

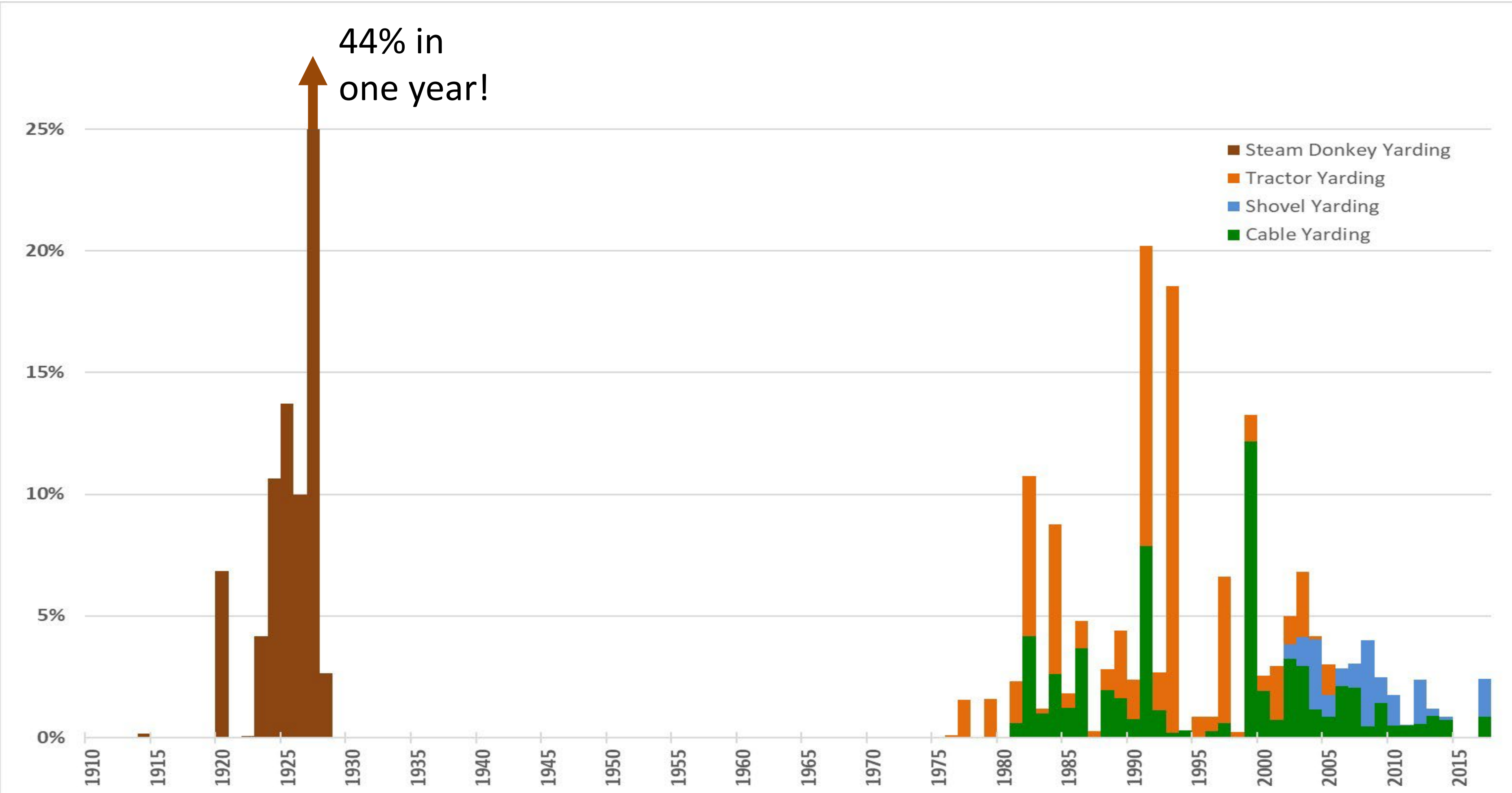
Acknowledgements

- Financial support primarily from California Department of Forestry and Fire Protection with some funds from NCASI;
- Tremendous logistical and some financial support from Green Diamond Resource Company;
- Many contributors:
  - David Lamphear, GDRCo: Harvest history, GIS analyst;
  - Jason Woodward, GDRCo: Geology and mass movements;
  - Drew Coe and Will Olsen, Cal-Fire: Road history;
  - Jeremy Wright, GDRCo: Current road conditions and connectivity;
  - Eric Clark, CSU: Road erosion modeling;
  - Jonathan O'Connell and Melissa Reneski, GDRCo: Runoff and suspended sediment yields;
  - Ken Ferrier (University of Wisconsin) and Patrick Belmont (Utah State University): beryllium-10 sampling and analyses;
  - Sean Gallen, Colorado State University: geomorphology and terrain analyses.

Lower South Fork (LSF) and Upper South Fork (USF) generally very similar:

- 13.8 and 14.7 km^2 for the LSF and USF, respectively;
- Mean elevation ~330 m; total relief ~550 m;
- Mean rainfall ~1600 mm yr^{-1};
- Mean slopes of 41 and 39%, respectively;
- Bedrock primarily fine-grained argillic sandstone;
- Soils are 50-60% loams, with slightly more fine-textured soils in the Lower South Fork;
- Nearly identical management history;
- But very different shape!
  - Length/width ratio about 4 in LSF and 1.4 in USF.

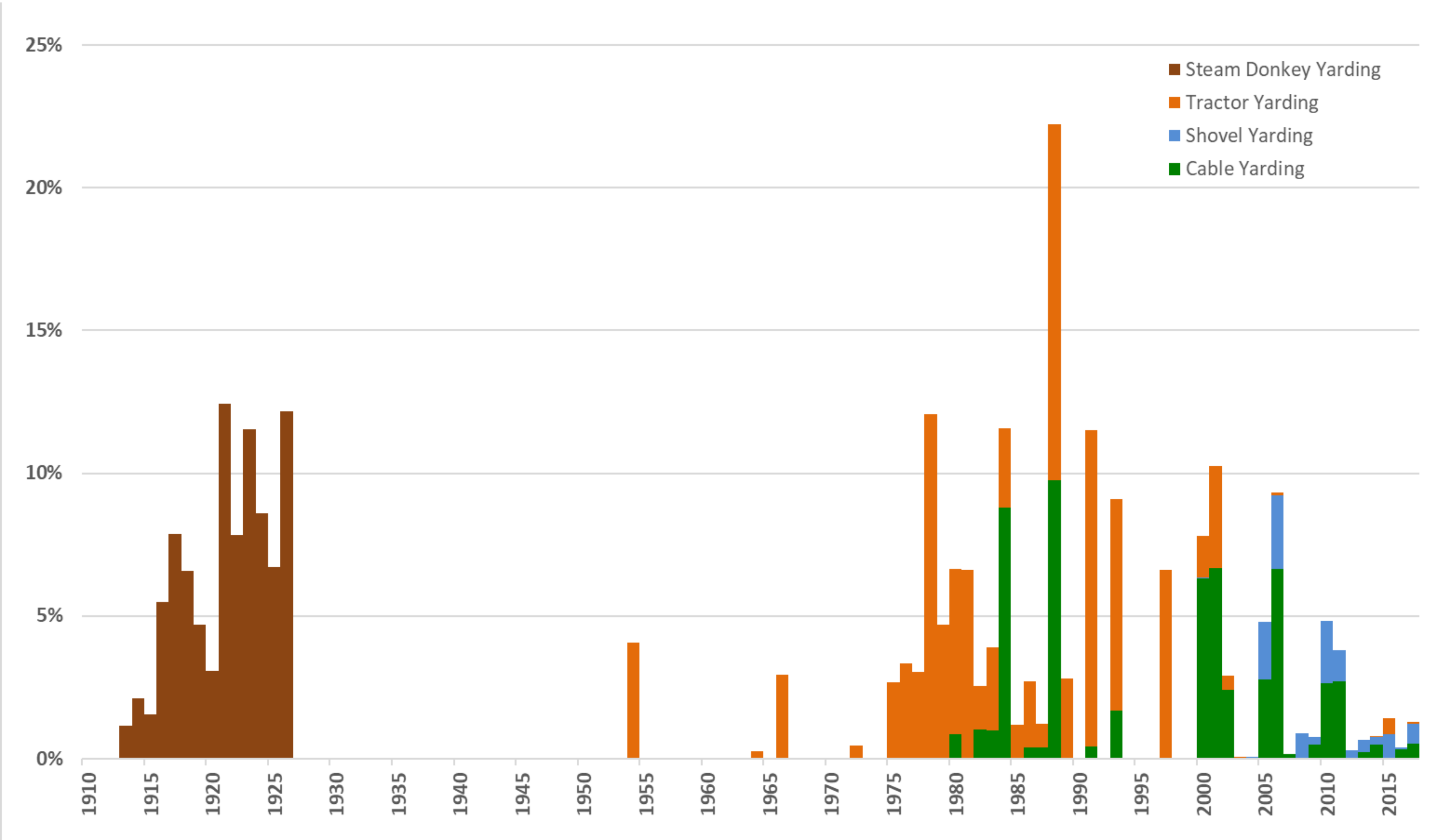
Timber harvest in Lower South Fork, 1910-2017:
Percent harvested by year and type of yarding



Cut 92% of old growth

Cutting second growth

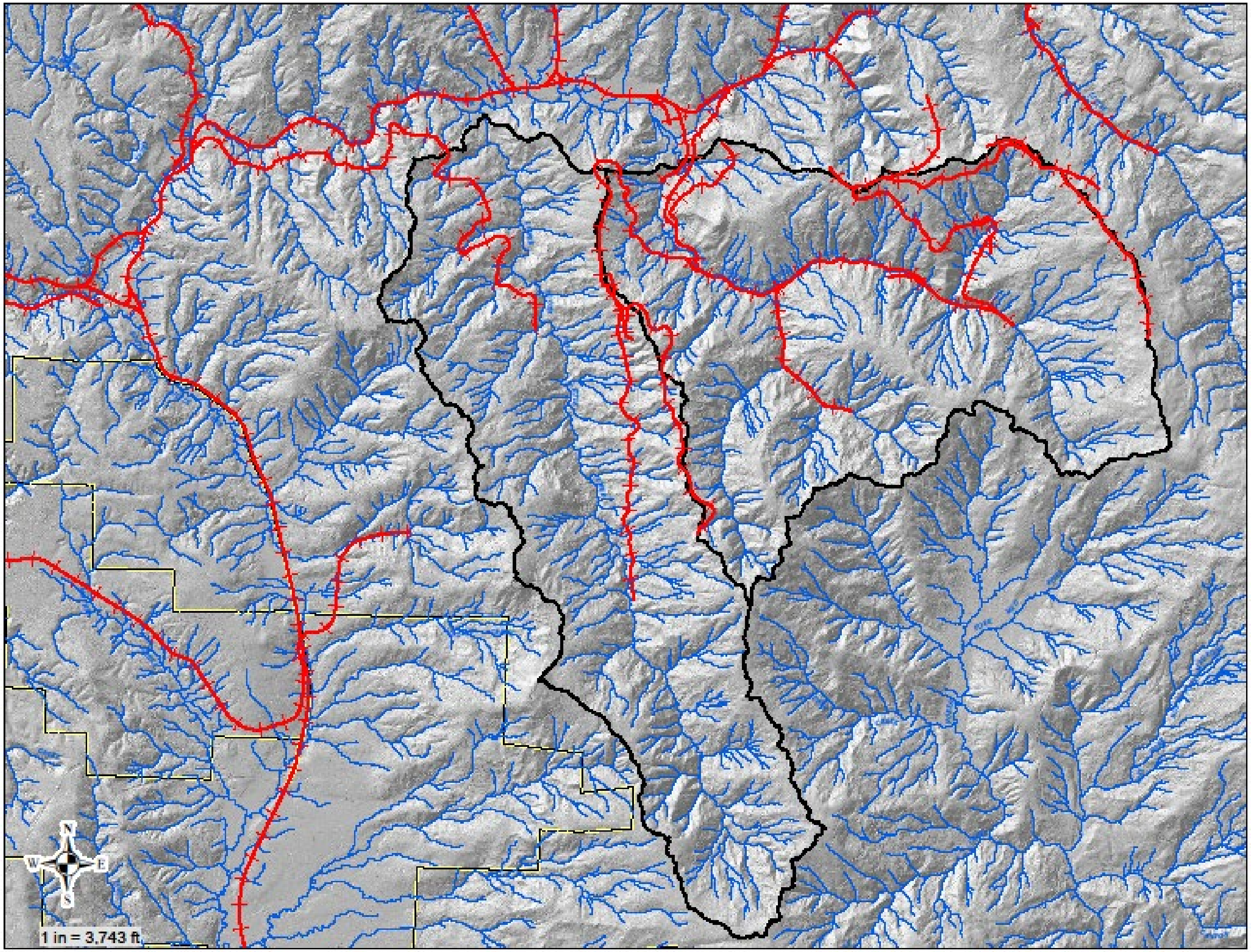
Timber harvest in Upper South Fork, 1920-2017:
Percent harvested by year and type of yarding



Cut 92% of old growth

Cutting second growth

Railroad network from lidar and old maps



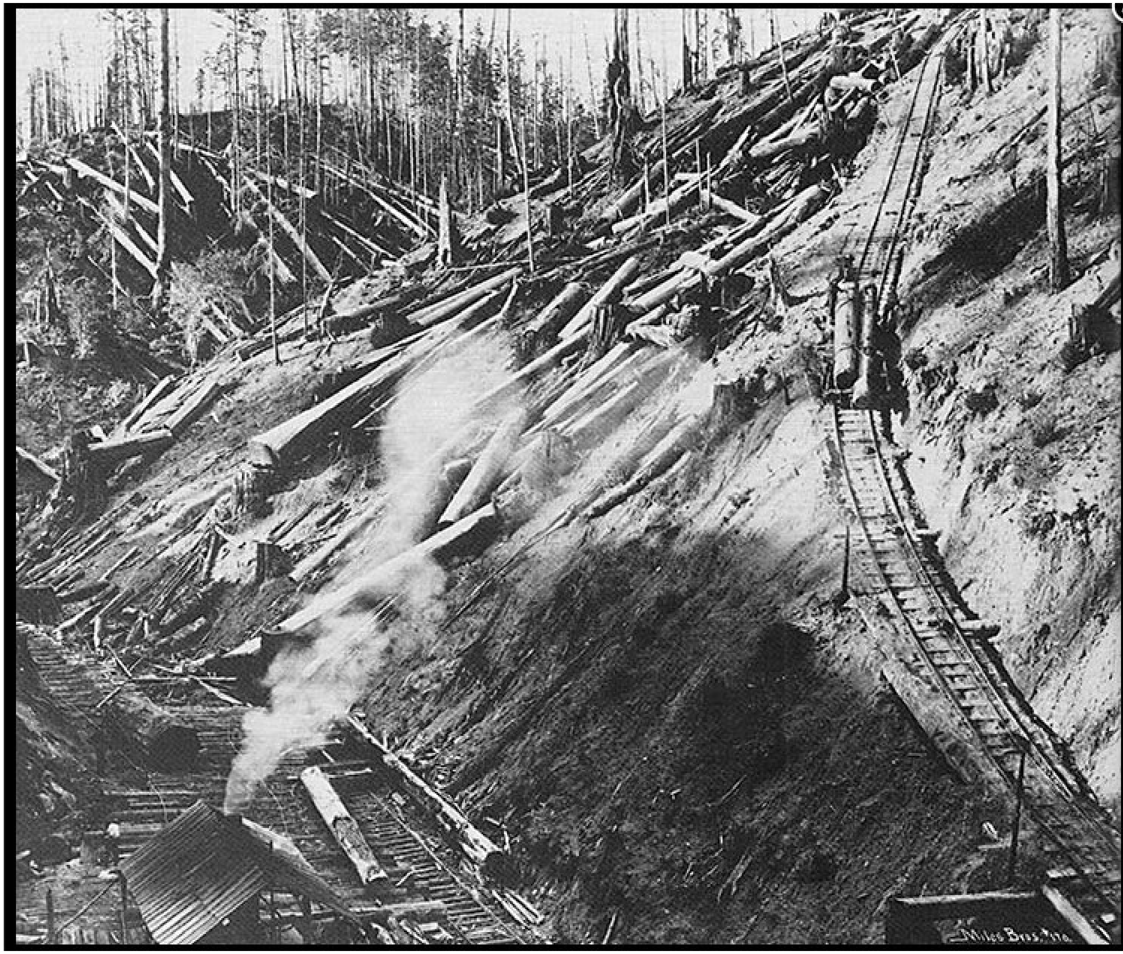
More railroads in Upper South Fork, especially in the valley bottoms

Railroad lines usually used trestles, so less ground disturbance than roads

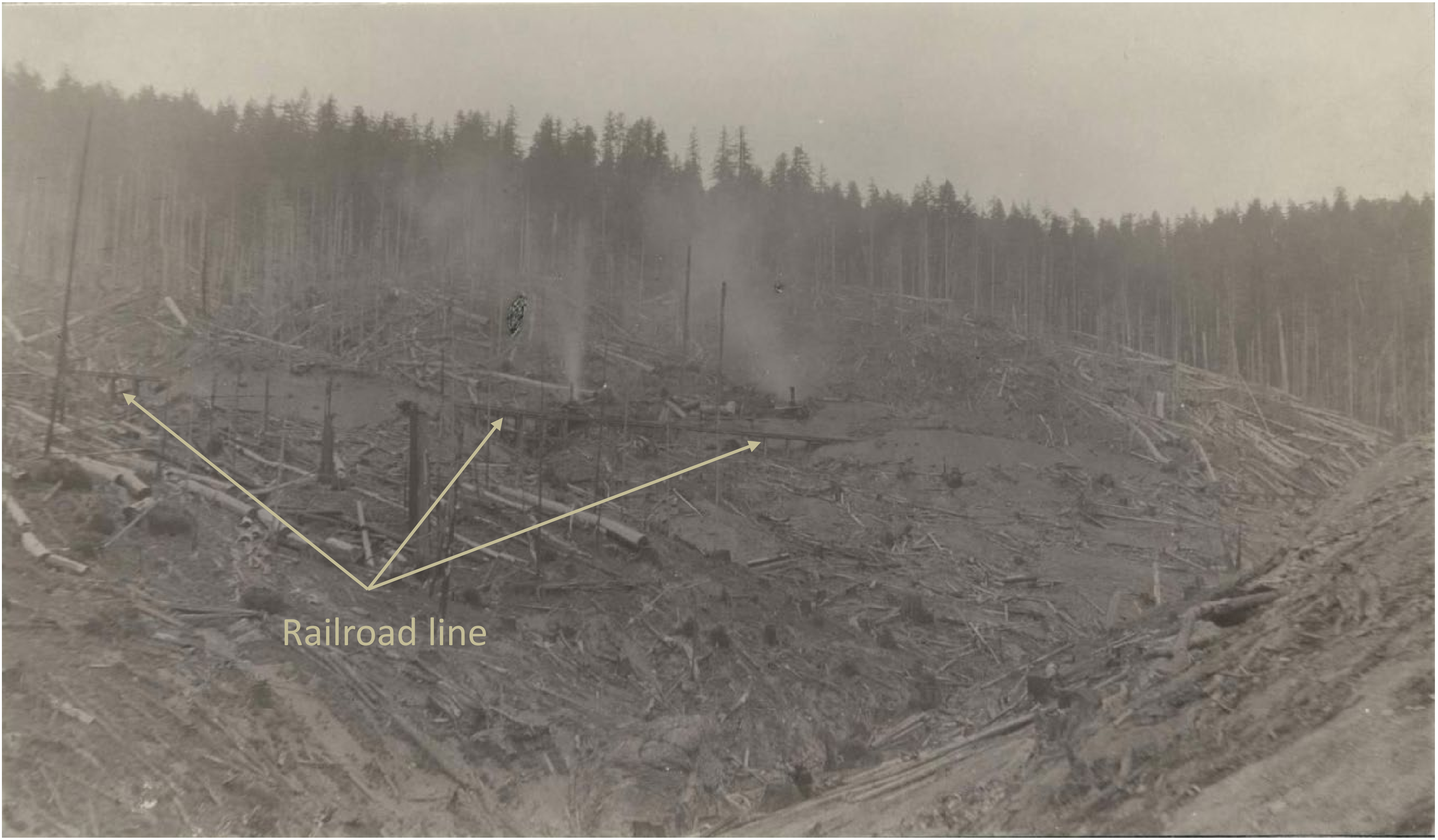
Little River

"Steam donkeys" were used to winch logs to a landing for loading onto the railroad

Inclines were major pathways for winching logs down to the railroad for loading



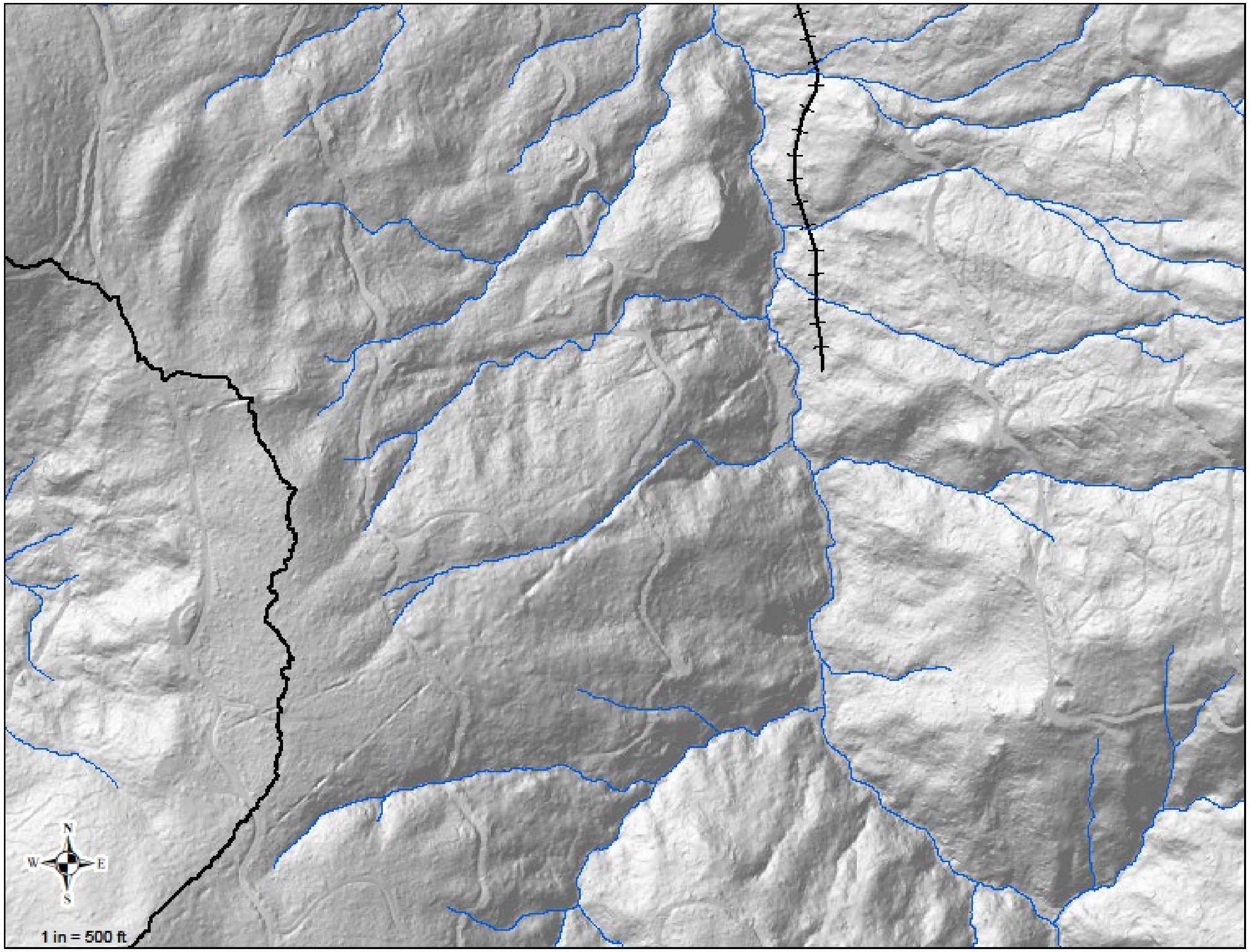
Harvested area in Little River in 1923
Note railroad line just below the two steam donkeys



4.2344. Fritz-Metcalf photograph collection

In steeper areas “high lead” cable systems conveyed logs to a landing for loading onto the railroad

Lidar showing railroad lines, inclines, roads, and old skid trail networks



We infer that railroads and inclines caused severe but localized ground disturbance. No layouts, large tractors were not being used to move logs or build roads, and no road network.

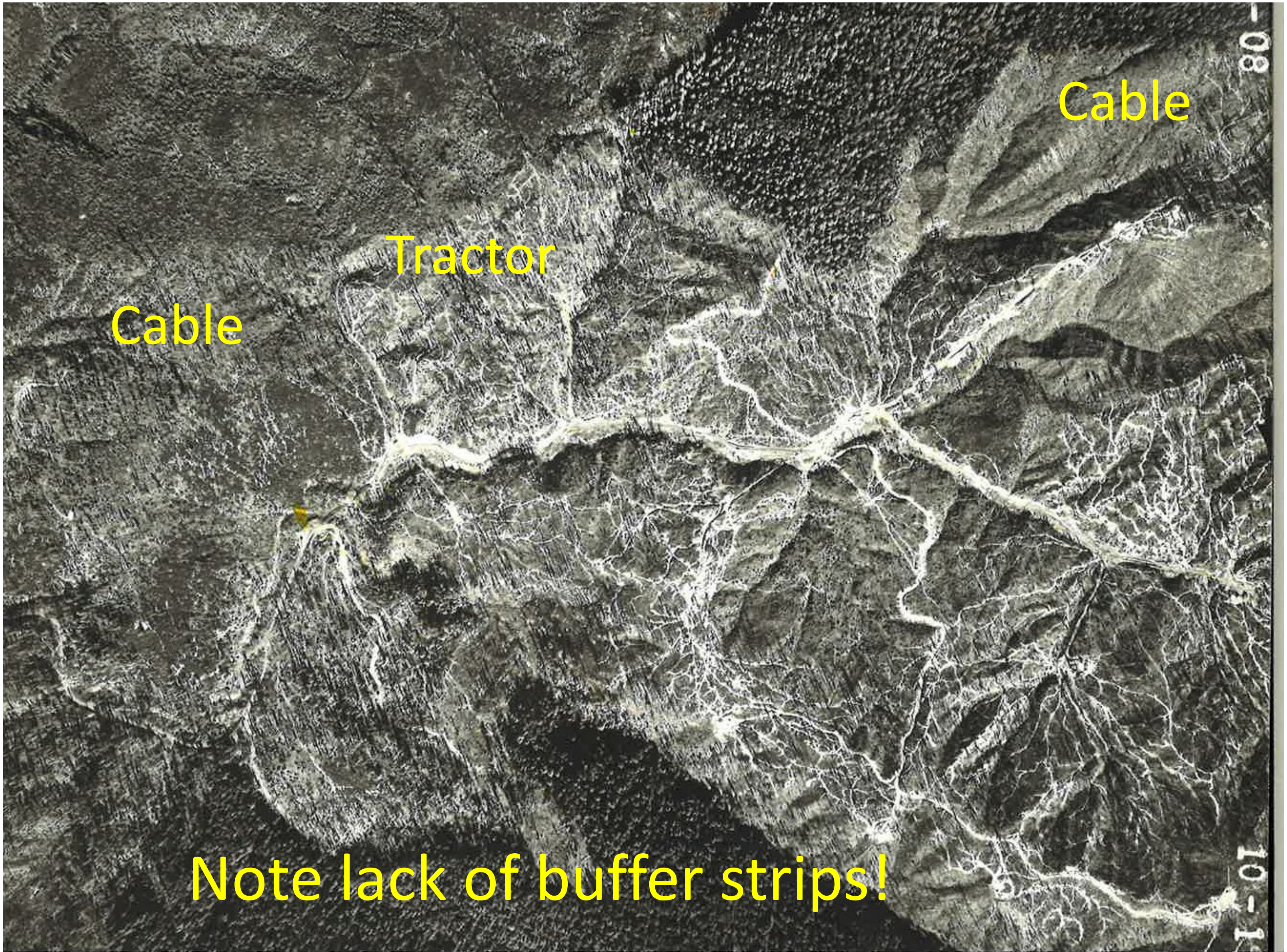
Management history: Second entry

- Nearly a 50-year gap until the second growth began to be harvested;
  - Railroad lines were converted to main haul roads and a dense road network was built;
  - Most of the earlier second growth logging was done with tractors, so extensive and sometimes severe ground disturbance;
  - Cable yarding only when slopes were greater than 40-50%;
  - Mixture of clearcuts and selection harvest.

Forest practice rules in California: 1973-2018

- Sedimentation in places like Redwood Creek was a major impetus to the development of forest practice rules
- Initial focus was to retain some canopy along fish-bearing streams to prevent water temperature increases;
  - In the early years these rules were typically not applied in areas with coastal fog like Little River ("fog exemption").

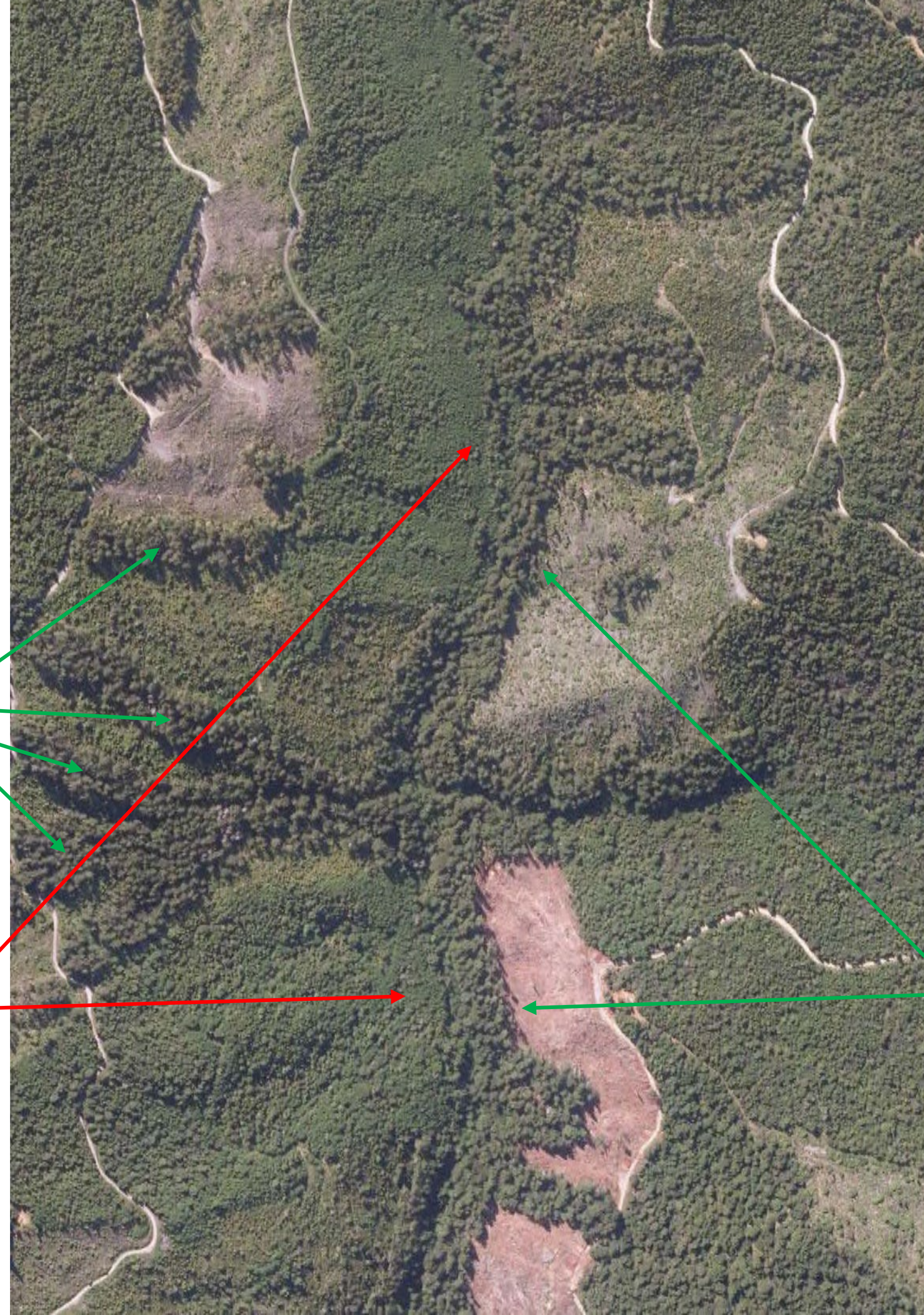
1980 aerial photo showing relative ground disturbance due to tractor versus cable yarding



Forest practice rules in California: 1975-2018

- More stringent regulations over time:
  - Increased size and retention in buffers, and limitations on tractor use in ephemeral streams and swales;
  - Smaller clearcuts;
  - Lower allowable rates of timber harvest;
  - Requirements to rock roads for winter use, crossings had to be designed for 100-year flood, etc.;
- Beginning in 2001 the Little River Management Plan, followed by an Aquatic Habitat Conservation Plan, led to GDRCo-specific rules to protect fish, rocking and stormproofing roads, road decommissioning, and measuring suspended sediment yields.

Changes in the extent and width of riparian buffers: Headwaters of Upper South Fork



Buffer strips

No buffers on other side!

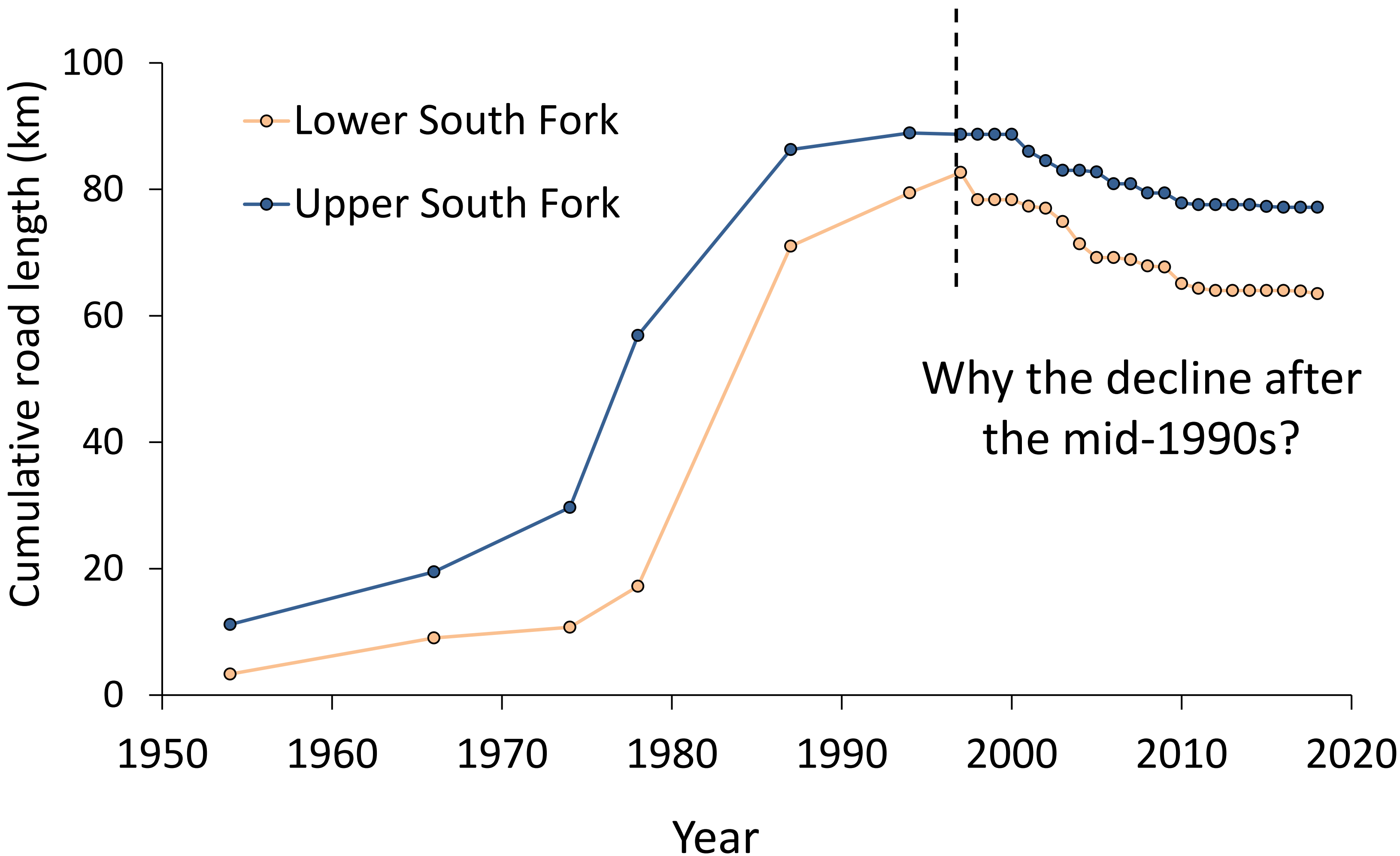
Buffer strips

Management history: Part 3

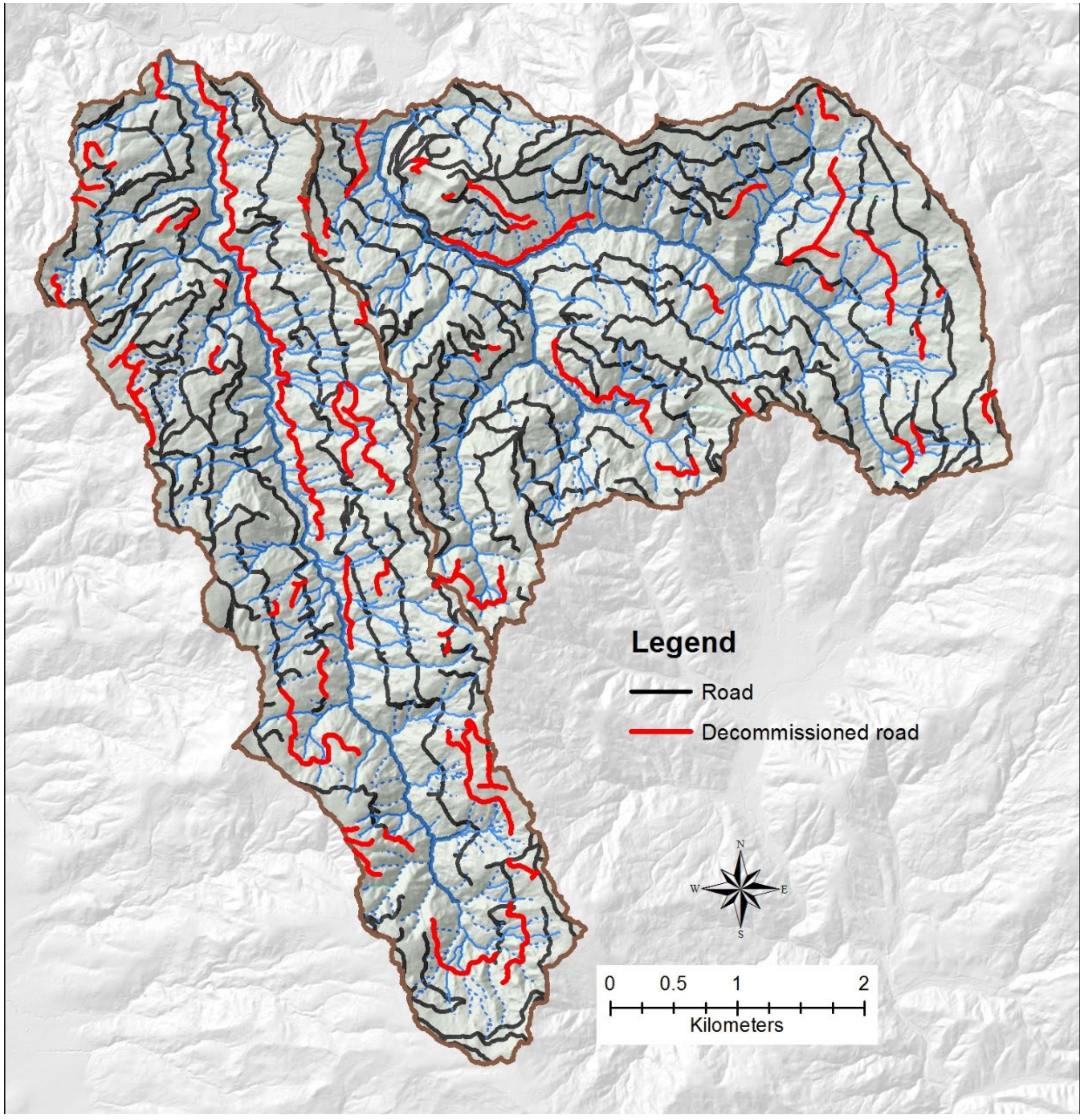
- Since about 2006 Green Diamond has been using “shovel logging” for ground-based harvests;
- No tractors dragging the logs to a landing;
- Almost no soil disturbance or compaction other than the temporary roads used by the trucks;
- Nearly 100% ground cover after harvest.

Current timber harvest practices believed to generate and deliver very little sediment

Road construction over time matches harvest history



Extensive road decommissioning:
Shifting roads from the valley bottoms to the ridgetops



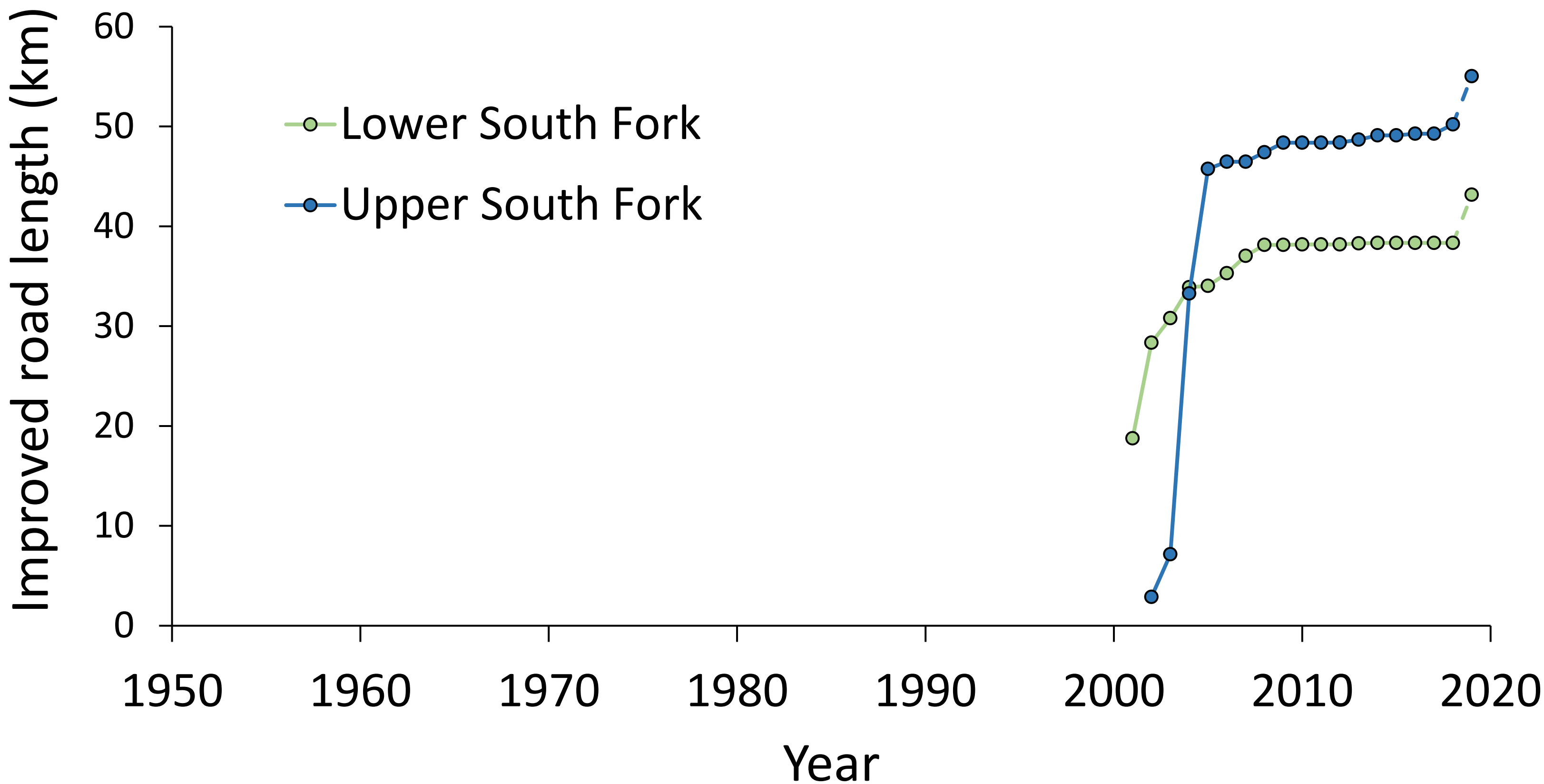
Nearly 20 km of roads decommissioned in the LSF;

Almost 12 km in the USF.

Typical native surface road being used in wet conditions: circa 1990

Same road after rocking and improved drainage: 2001

Road improvements over time
(rocking, improved drainage, bigger culverts, etc.)



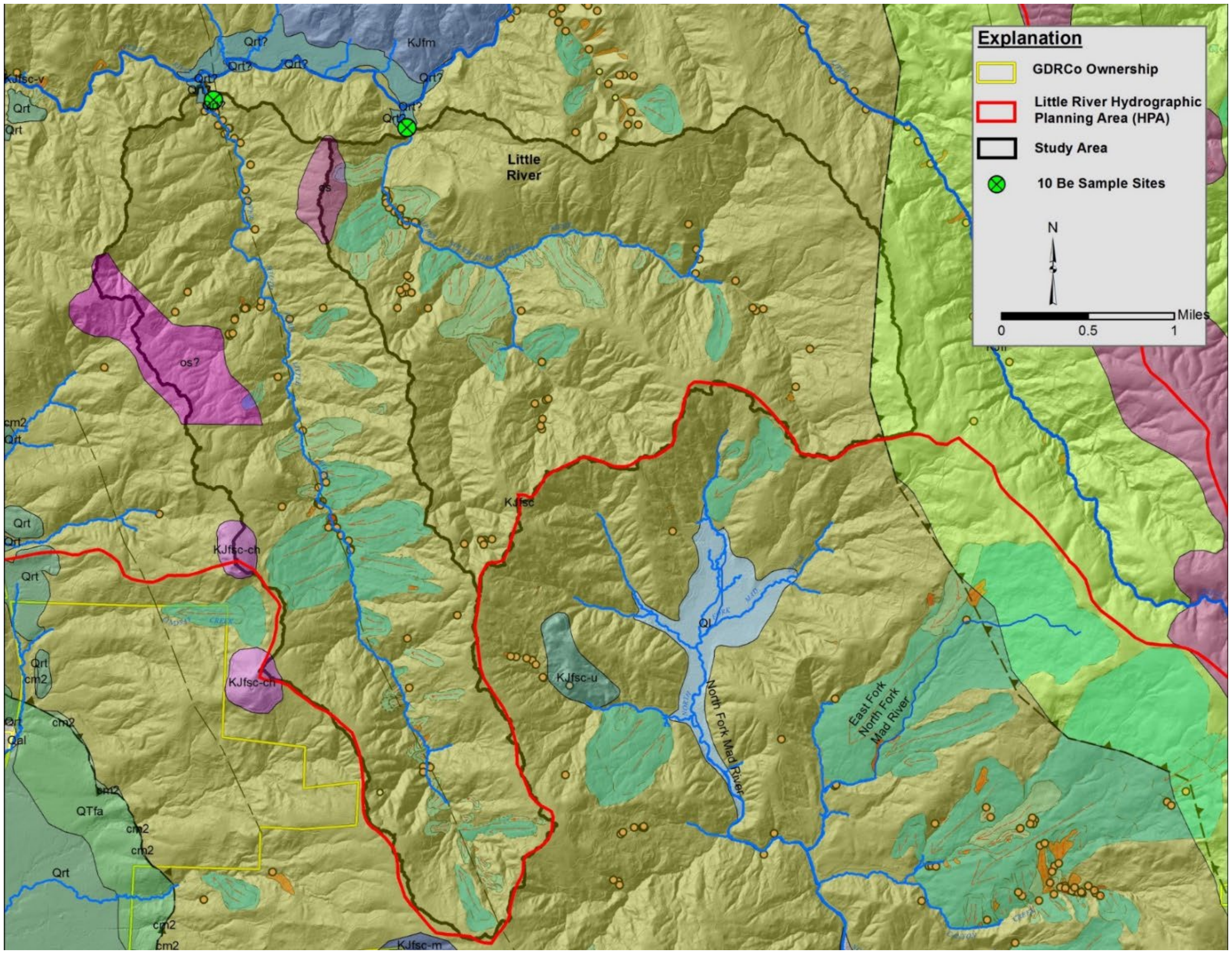
Timing of road improvements driven by the Little River Management Plan and then the Aquatic Habitat Conservation Plan

Sediment source: unpaved roads

- Decline in road sediment production and delivery due to rocking most roads, reducing winter traffic, more frequent drainage, fewer road crossings, and decommissioning roads next to a stream;
- Proportion of roads draining directly to a stream has dropped from 74% in 1997 to 15% today;
- GRAIP-Lite modeling indicates that roads currently contributing about 10 and 7 Mg km^{-2} yr^{-1} for the LSF and USF, respectively (~20-30 tons mi^{-2} yr^{-1}).

Sediment source: Deep-seated landslides (in green)

- About 10% of watershed area;
- All are classified as dormant, mostly dormant-mature.



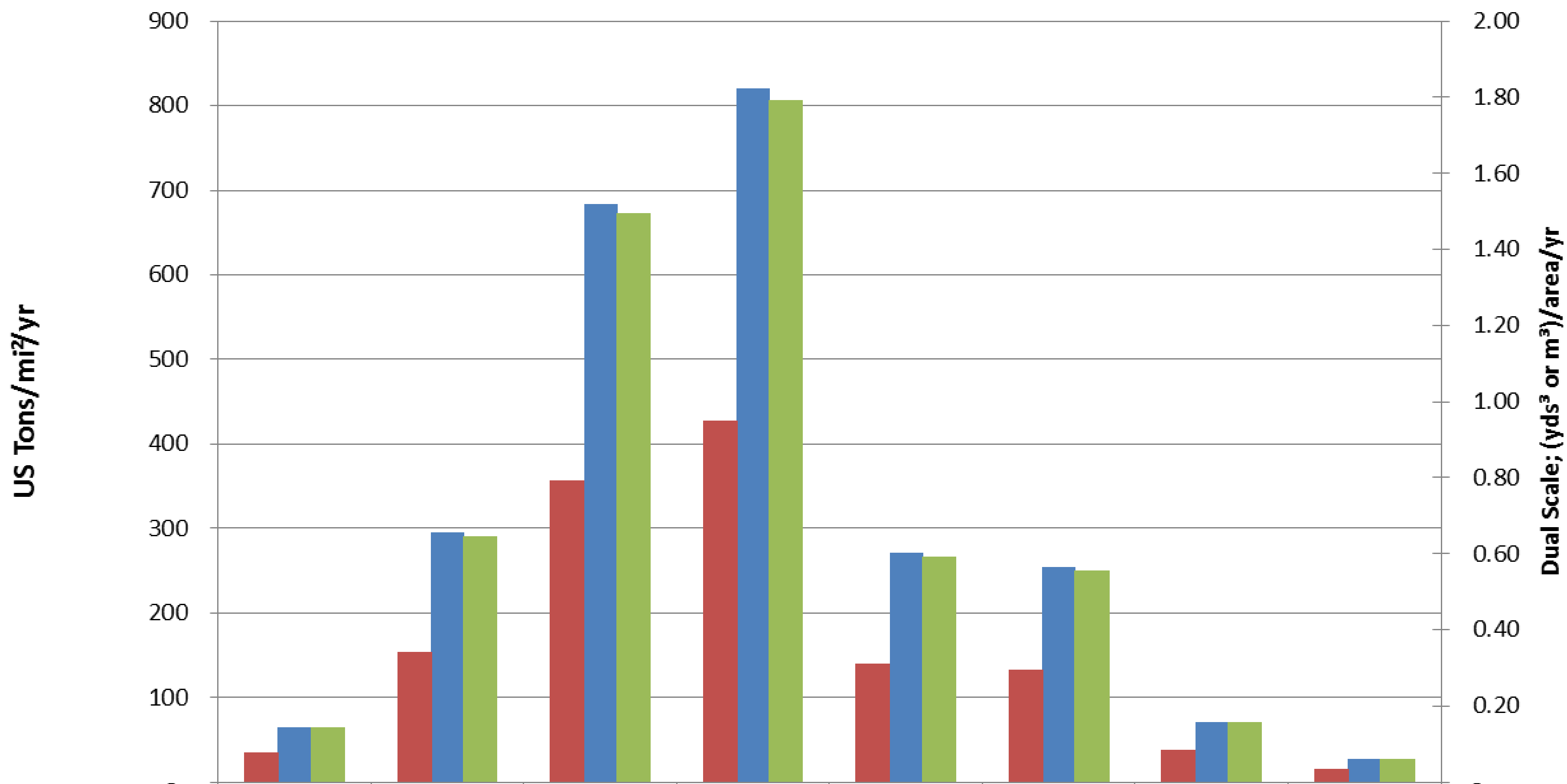
Unlikely to be a large sediment source (< 10 Mg km^{-2} y^{-1})

Sediment source: shallow landslides

- Aerial photo analysis and limited field surveys along streams identified and measured ~60 shallow landslides in each watershed;
- Only 18% in harvested units and just 7% from roads;
- About half of the total eroded volume is delivered to a stream;
- Total mass of sediment delivered from shallow landslides in each watershed highly uncertain due to limited sampling and uncertain dates of occurrence;
- Initial calculations suggest that shallow landslides are probably the largest sediment source, but more sampling is needed.

Incidence of shallow landslides over time

All Green Diamond ownership in northwest California



	1940's	1950's	1960's	1970's	1980's	1990's	2000's	*2007-2012
US Tons/mi²/yr	66	296	684	820	270	255	72	28
yds³/acre/yr	0.08	0.34	0.79	0.95	0.31	0.29	0.08	0.03
m³/ha/yr	0.14	0.65	1.50	1.79	0.59	0.56	0.16	0.06

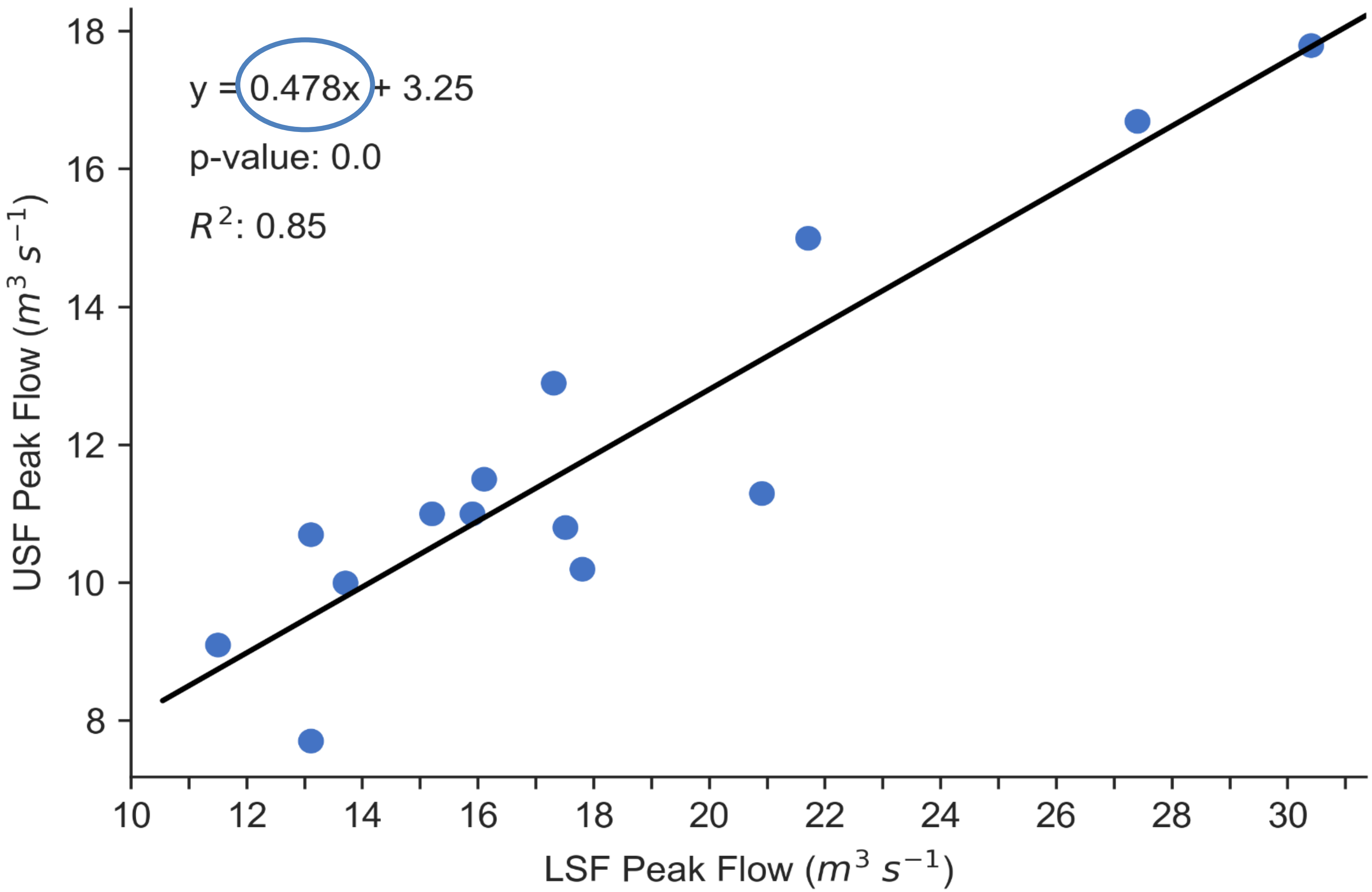
x160 to get Mg km^{-2}!

Sediment source: bank erosion

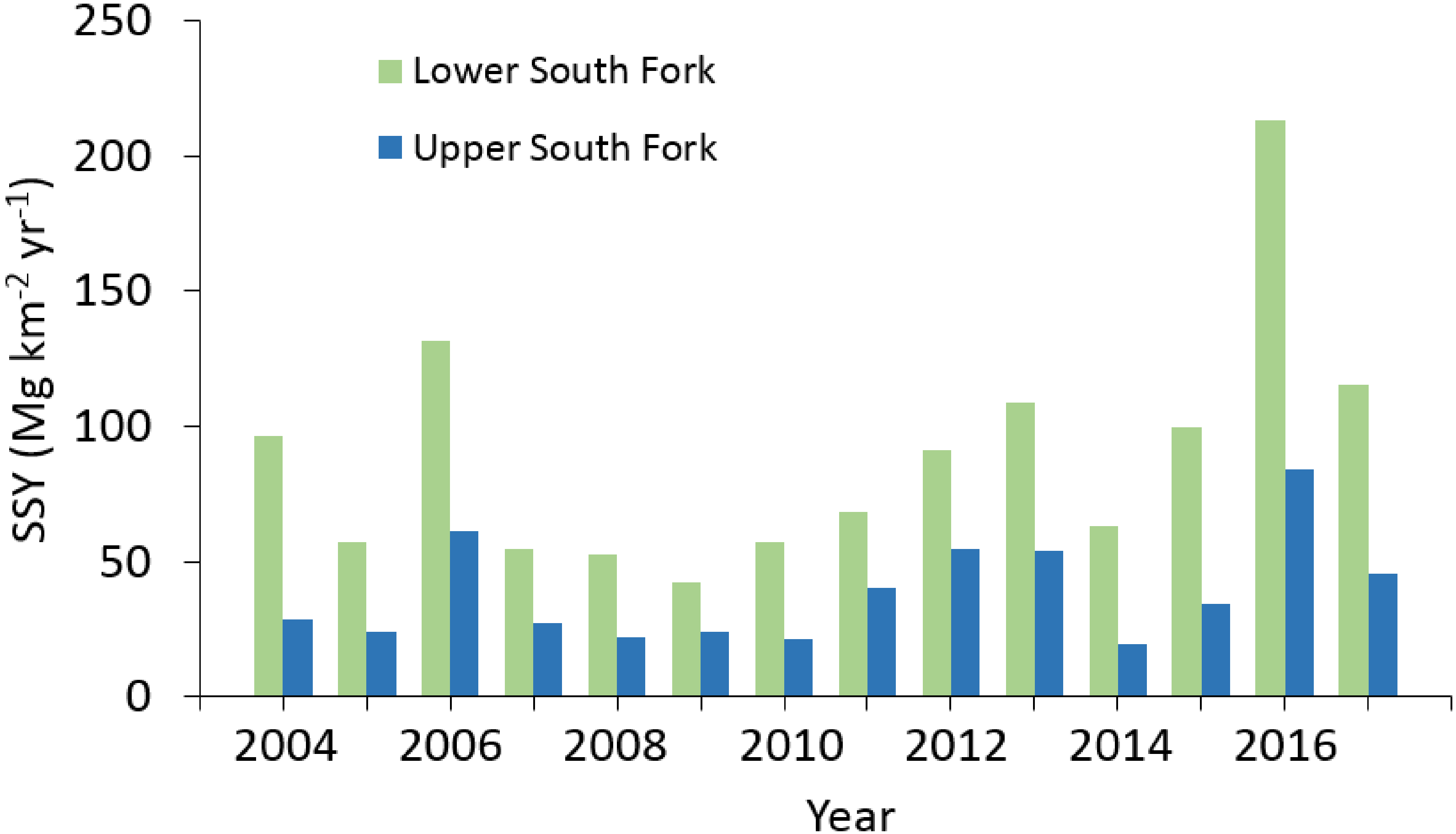
- Surveyed 1.1 km of streams in the LSF and 2.8 km in the USF;
- Very limited sample and uncertain dates make watershed-scale estimates highly uncertain;
  - <3 Mg ha^{-1} yr^{-1} in LSF;
  - ~10 Mg ha^{-1} yr^{-1} in USF;
- Results suggest that bank erosion is not a major sediment source, but more sampling is needed.

Gaging station results: Peak flows and suspended sediment yields

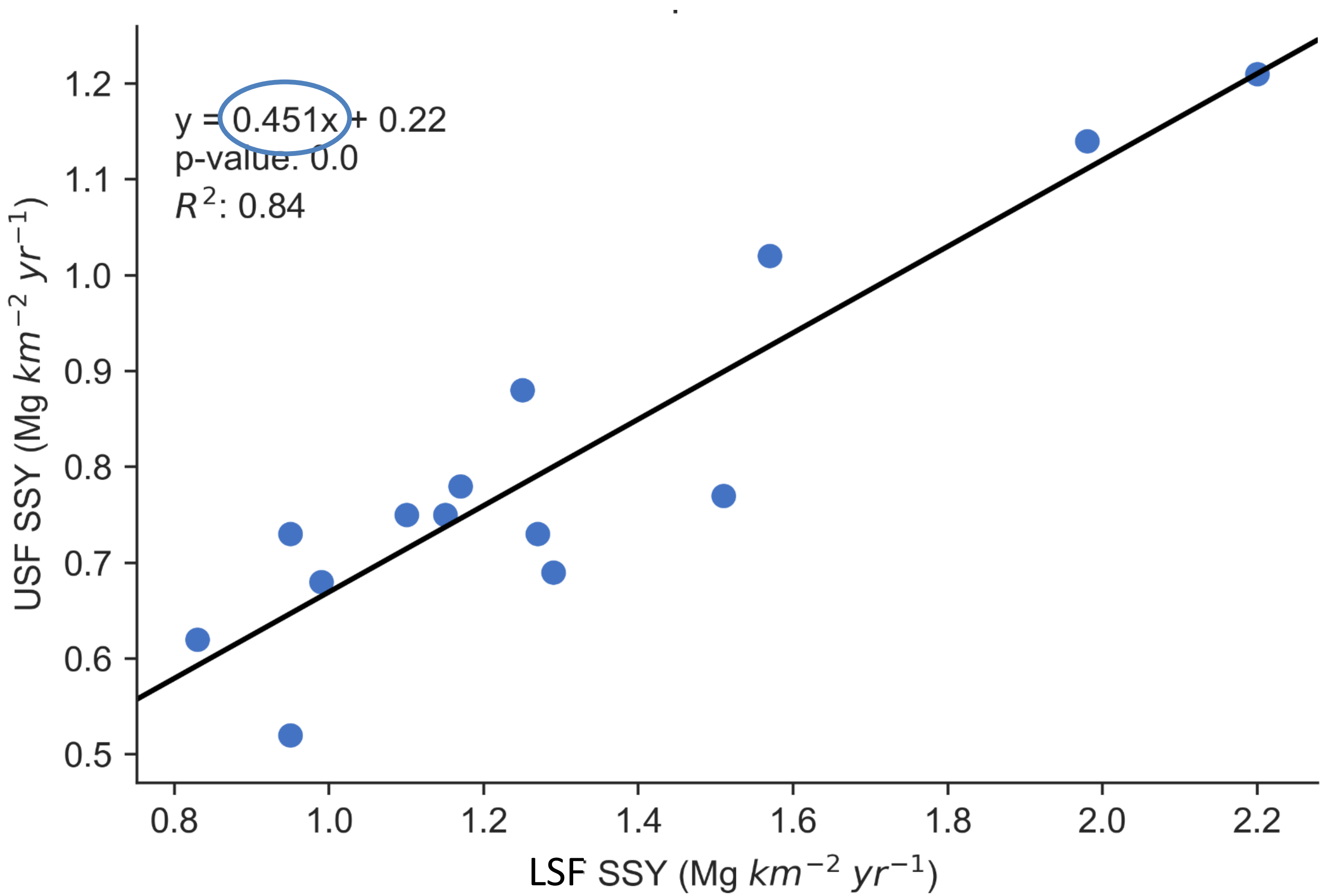
Peak flows are highly correlated, but are twice as high in the Lower South Fork



Comparison of annual suspended sediment yields: 2004-2017



Suspended sediment yields highly correlated, but 2.2 times higher in the Lower South Fork



Fish population monitoring

Summer population surveys

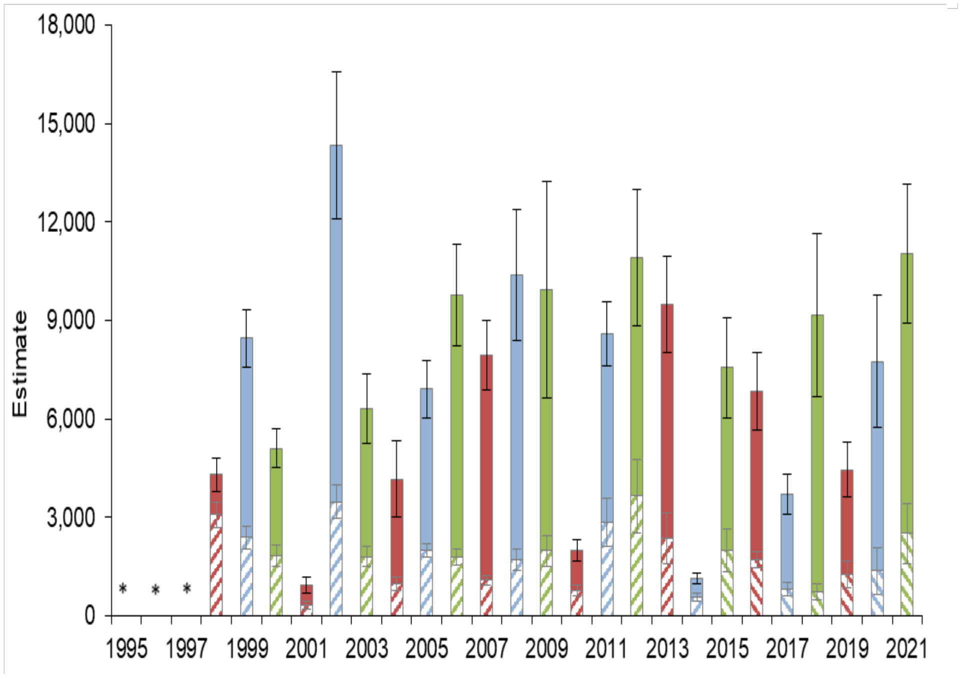
Out-migration trapping

Results of fish monitoring: 1998 to present

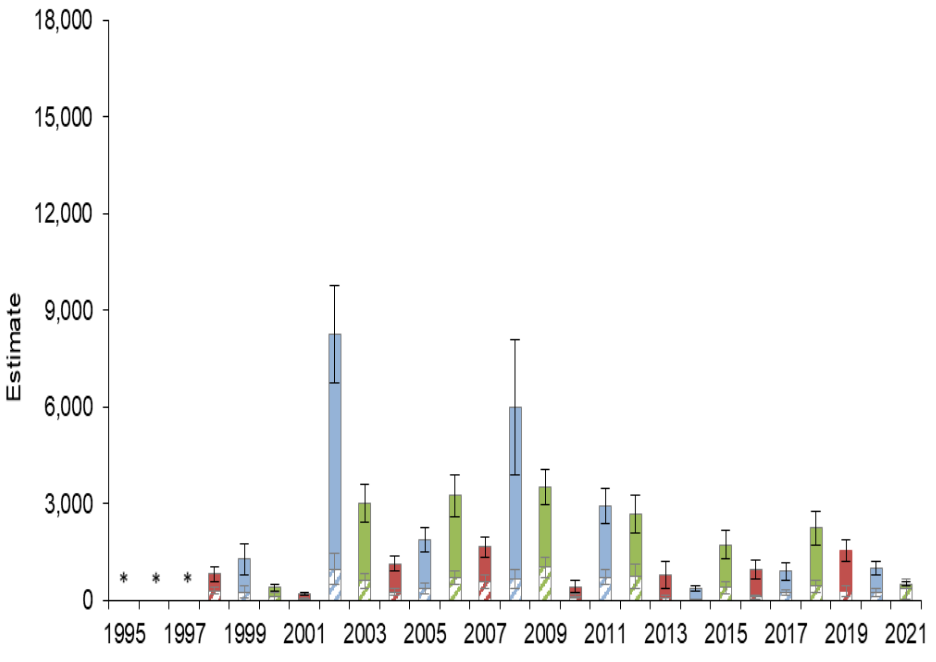
- No clear trends in fish populations over time;
- Lower South Fork has about three times more fish!

Summer juvenile coho populations

Lower South Fork



Upper South Fork

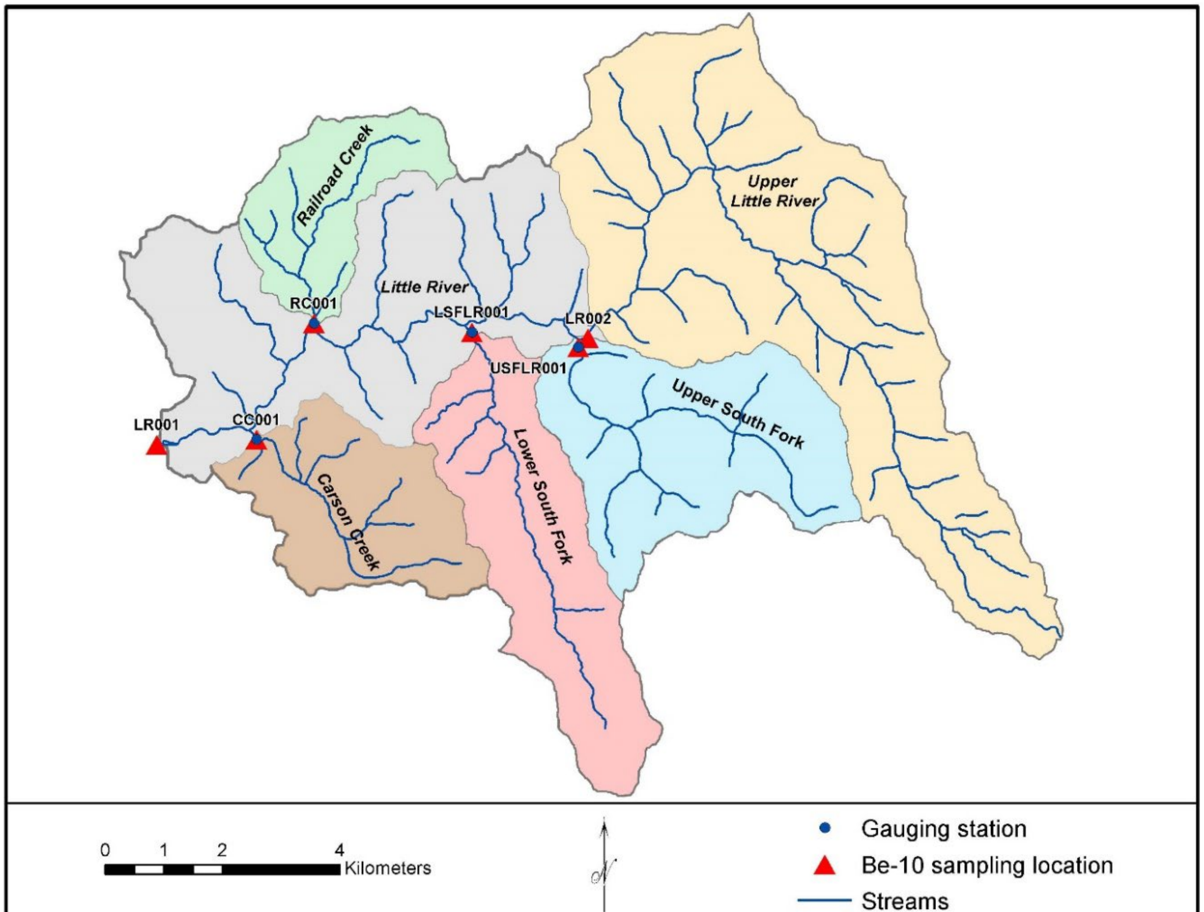


Why ~3x more salmonids in the LSF?

- Similar number and size of pools;
- LSF has 35% more stream length with fish;
- Probably the biggest factor is that the LSF has more than twice as much large woody debris;
- Noteworthy that outmigrant numbers are substantially lower in years after very high peak flows.

Millennial scale erosion

- Using a cosmogenic isotope (beryllium-10) to determine millennial-scale denudation rates;
  - Sampled the mouth, the four tributaries with gaging stations, and area upstream of the study watersheds;



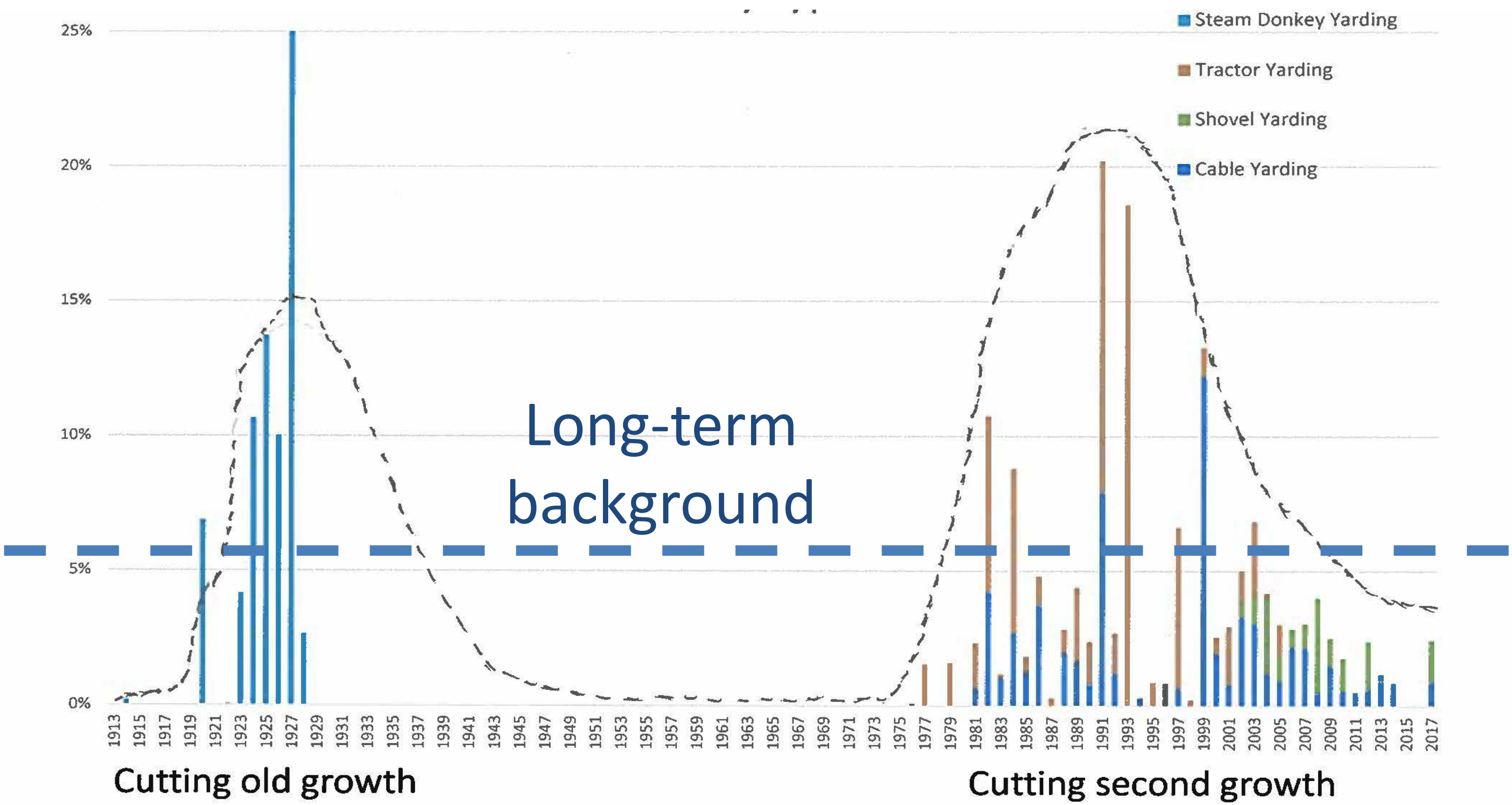
Long-term erosion rates (~5000 years)

- Results were relatively consistent, with higher rates in the steeper watersheds and lower rates in the flatter watersheds;
- Value for the entire Little River watershed was 200 ± 60 Mg km^{-2} yr^{-1};
- Value for the Lower South Fork was relatively high at 260 ± 76 Mg km^{-2} yr^{-1}, while the value for the Upper South Fork was less than half (110 ± 80 Mg km^{-2} yr^{-1});
- After adding estimated bedload and dissolved loads, long-term erosion rates for the four gaged watersheds are consistently just over twice the measured mean suspended sediment yields for 2004-2017.

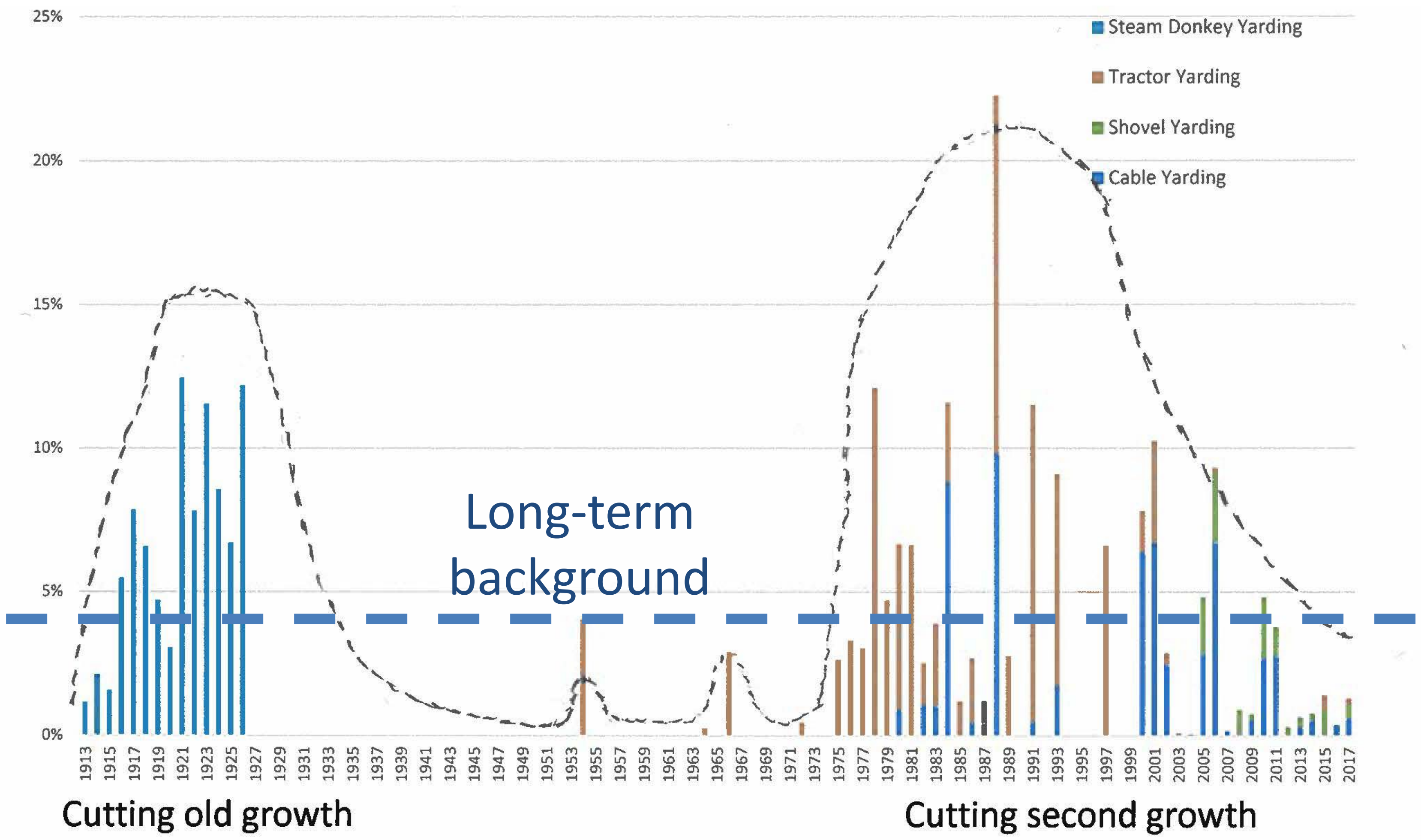
Be-10 results and measured sediment yields

- Be-10 values are consistent with the estimated uplift rate of 0.1-0.2 mm/yr (Balco et al., 2012);
- Coarse stream substrate, relatively competent geology, and lack of cross-section channel change all suggest that sediment yields are limited primarily by sediment supply rather than sediment transport capacity.

Inferred management-related sediment yields over time: Lower South Fork



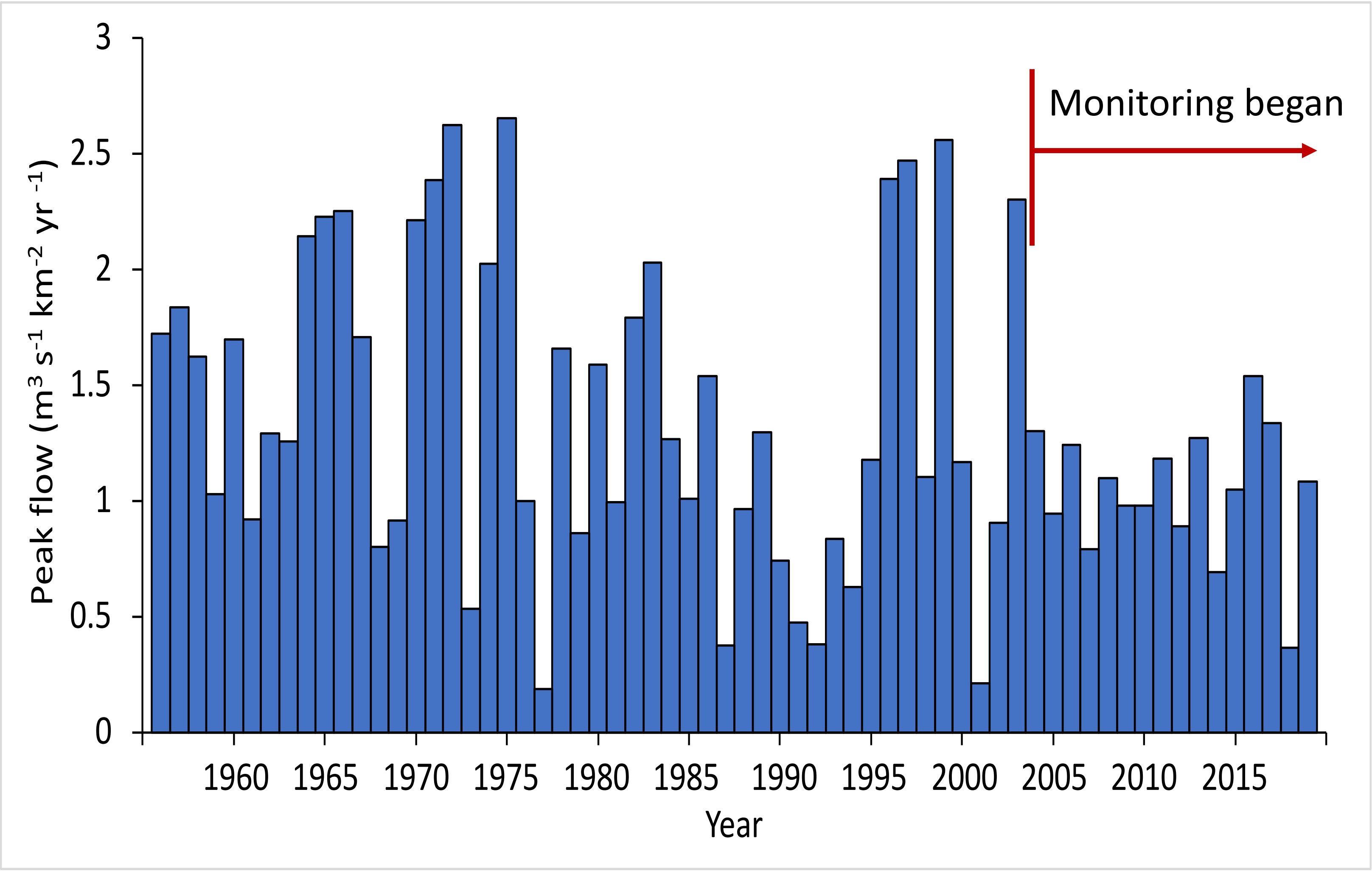
Inferred management-related sediment yields over time: Upper South Fork



Why is there such a large difference between the short-term measured and long-term erosion rates?

1) Sediment yields follow a lognormal distribution, and the 14 years of monitoring have not had any big flows;

Peak flows: USGS gaging station, Little River



Why is there such a large difference between the short-term measured and long-term erosion rates?

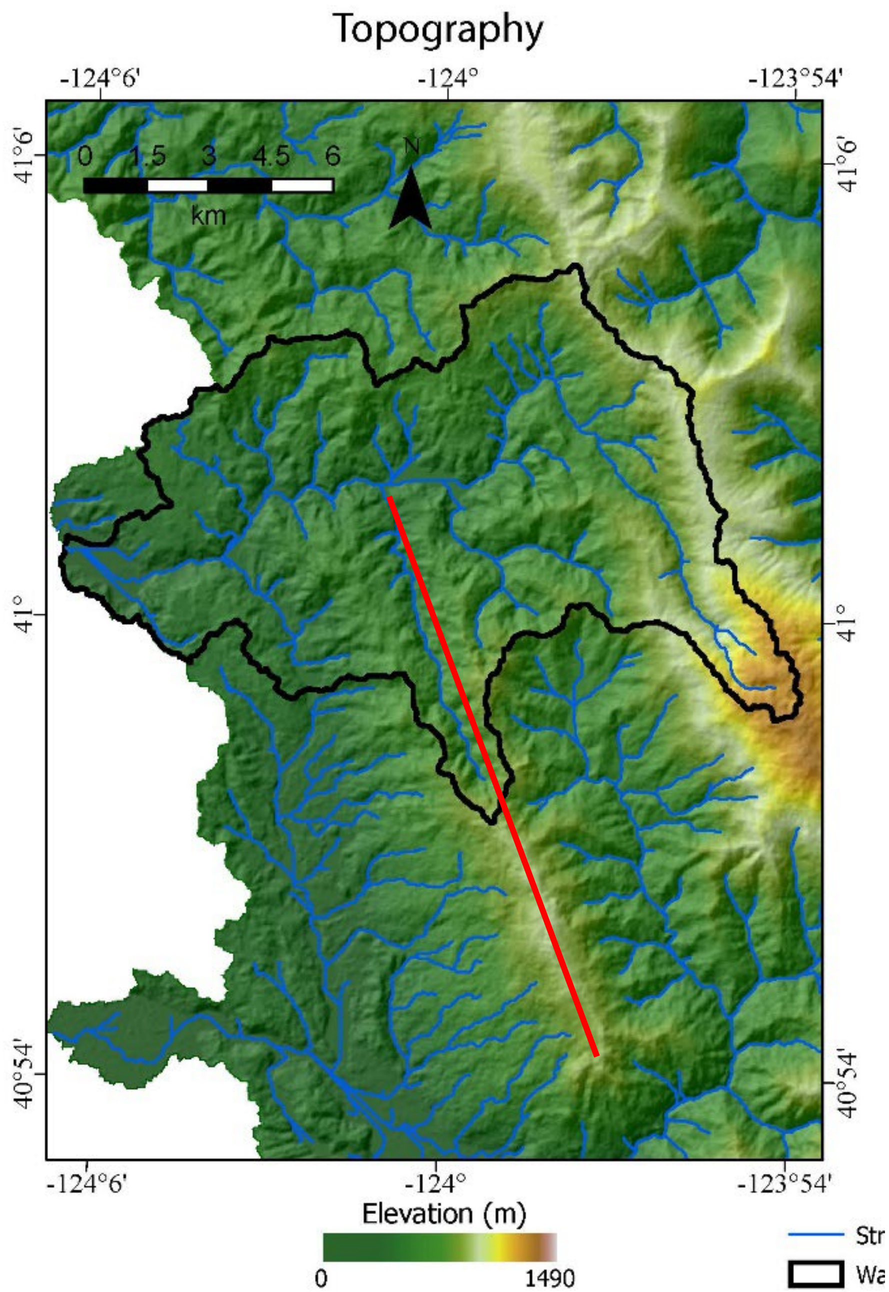
1) Sediment yields follow a lognormal distribution, and the 14 years of monitoring have not had any big flows;
2) Hypothesize that high long-term erosion rates are due to large numbers of landslides occurring after the infrequent combination of large earthquakes and extreme precipitation events. This is consistent with the 40% mean slope in the study watersheds and studies in other areas experiencing tectonic uplift and large earthquakes (e.g., Himalayas, Taiwan).

Why are short-term suspended sediment yields and long-term erosion rates so much higher in the Lower South Fork than the Upper South Fork?

- Higher peak flows in the LSF can mobilize and transport more sediment;
- Likely unmapped fault along the axis of the LSF, and lower rock strength may also be facilitating higher erosion rates;
- LSF may be cutting into an anticline and a softer rock layer as indicated by regional scale folding and presence of a long linear ridge immediately to the south.

Regional topographic map and geology

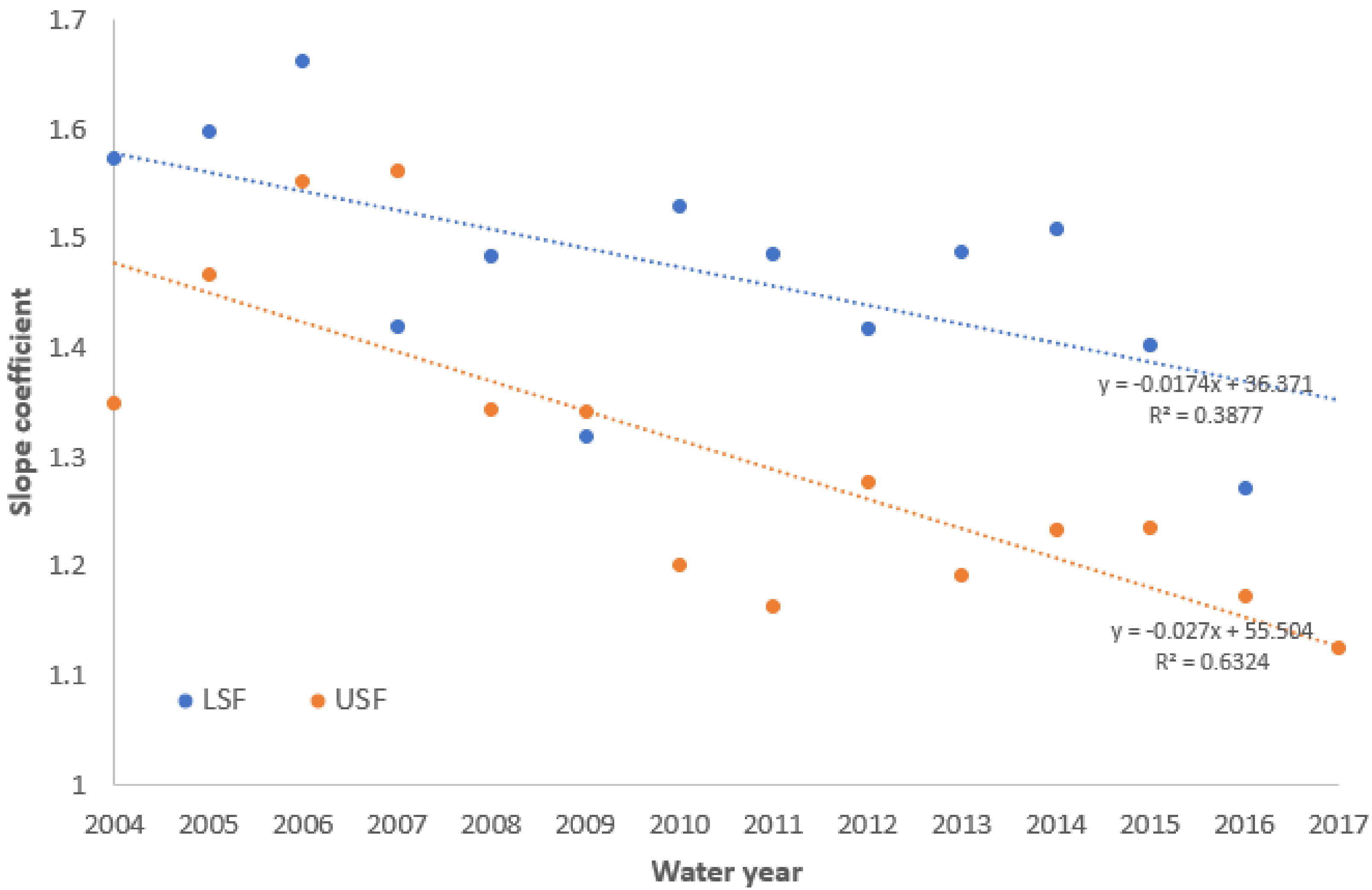
- Very odd that the valley of the Lower South Fork suddenly stops and quickly transitions to a ridge with a nearly identical compass bearing;
- Orientation of these features consistent with the faulting caused by subduction of the Gorda Plate under the North American Plate, and northward movement of the Pacific plate along the San Andreas fault.



Legacy effects: are they important?

- In the two study watersheds there is very little evidence of any legacy effect from the old growth or second growth logging;
  - No change in cross-sections, or particle size in main channel draining these watersheds;
  - No evidence of legacy sediment deposits in the valley bottoms;
- Suspended sediment concentrations for a given turbidity do show a decline over time, suggesting some recovery;
- However, mean SSC values show no trend other than the first four years of monitoring have higher values than the following 10 years.

Change in turbidity (FNU) versus SSC slopes over time



Legacy effects: what about other watersheds?

- Redwood Creek is the prime example of very severe sedimentation resulting from the tractor-based harvest of the old growth before the implementation of forest practice rules;
- A legacy effect also is evident in Railroad Gulch in the Elk River, and legacy effects are probably exacerbated by being in the highly erosive Hookton formation;
- Big contrast with Little River, where the old growth was harvested using railroads and steam donkeys, with minimal roading and harvest until the mid-1970s.

Conclusions

1. Sediment yields from tractor logging from the 1970s through the 1990s are inferred to be higher than the initial railroad logging due to greater ground disturbance and connected dirt roads;
2. Current sediment inputs from management activities are relatively low;
3. Legacy effects and current management do not appear to be increasing suspended sediment yields or reducing fish numbers;
4. Lower South Fork has much higher peak flows and suspended sediment yields than the Upper South Fork, presumably due to faulting and watershed morphology, but more salmonids;
5. Higher long-term sediment yields suggest that extreme events drive long-term denudation, particularly shallow landslides;
6. Landslide rates are driven primarily by uplift rather than management, suggesting only limited potential to further reduce sediment inputs from forest management in the study watersheds.

Conclusions - 2

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2. Current sediment inputs from management activities are relatively low;
3. Legacy effects and current management do not appear to be increasing suspended sediment yields or reducing fish numbers;
4. Lower South Fork has much higher peak flows and suspended sediment yields than the Upper South Fork, presumably due to faulting and watershed morphology;
5. Higher long-term sediment yields suggest that extreme events drive long-term denudation, particularly shallow landslides;
6. Landslide rates are driven primarily by uplift rather than management, suggesting only limited potential to further reduce sediment inputs from forest management in the study watersheds;
7. More broadly, the type and timing of harvests can play a dominant role in the presence or absence of legacy effects;
8. Geology and uplift rates also can greatly affect the relative effects of forest management on erosion and sediment yields.

All watersheds are different, and each has their own story!

Questions?

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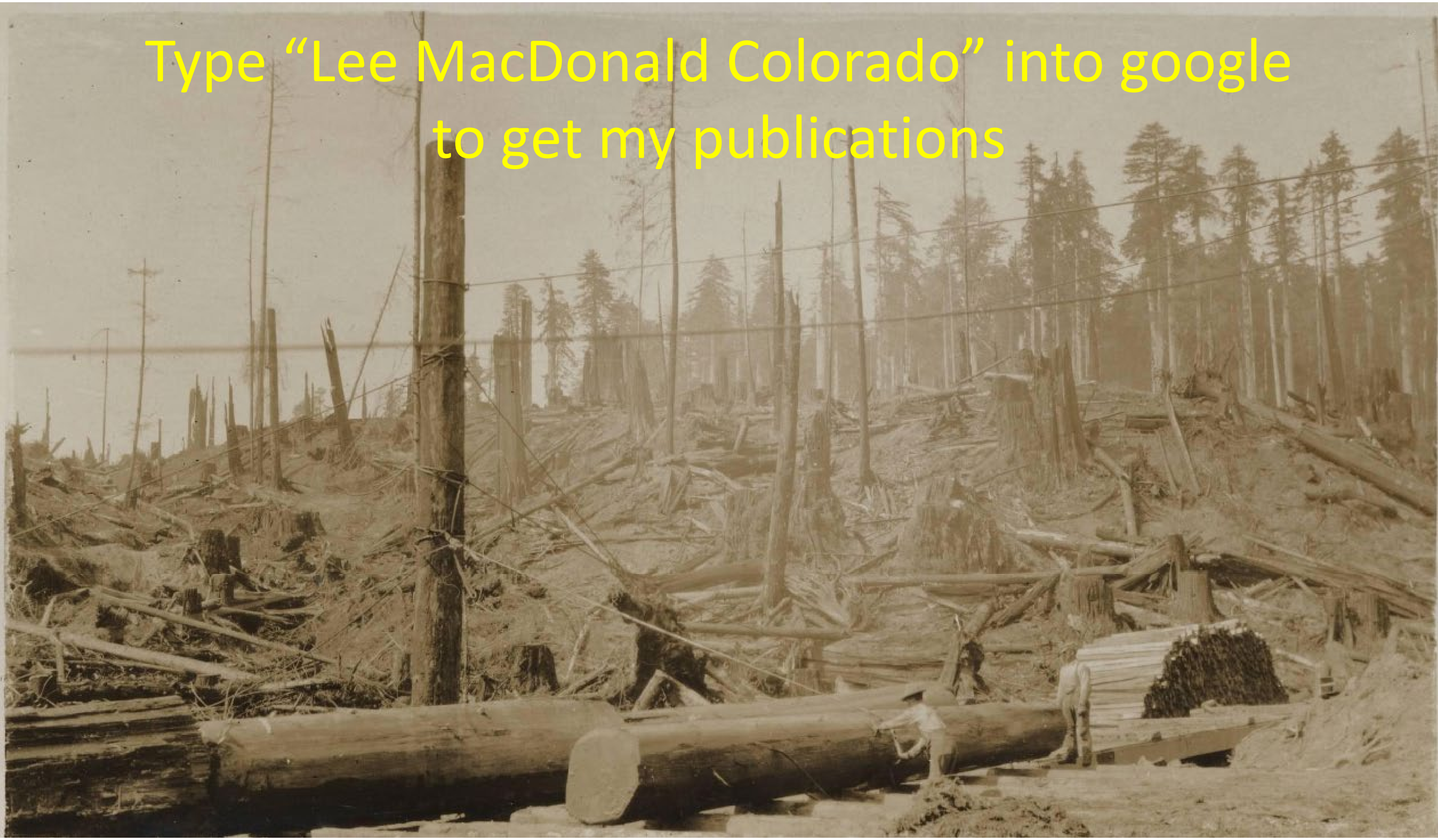

Loading logs onto railroad cars