

Science

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“Science affects the way we think together.”

Lewis Thomas

A LANDSLIDE IS A LANDSLIDE IS A LANDSLIDE... OR IS IT? DEFINING LANDSLIDE POTENTIAL ACROSS LARGE LANDSCAPES



Debris flows often transport wood and sediment from headwater streams and deposit it lower in the watershed, where it can affect fish habitat.

“To put your hands in a river is to feel the chords that bind the Earth together.”

—Barry Lopez

How do fish see their habitat? Particularly salmon, darting across interplays of light and dark in a cold mountain stream. Perhaps they can sense that their survival depends on habitat complexity: the cascades over logjams that excavate deep pools, the shallow riffles interspersed with overhanging streambanks around slow meanders that provide food and

cover. Stream complexity is born out of the physical forces of input and removal. Inputs are often sudden and dramatic—heavy rains force soil, boulders, and trees to give way in a landslide. These inputs are steadily rearranged then swept away by streamflow.

Kelly Burnett, a research fish biologist at the Pacific Northwest Research Station, and Dan Miller of Earth Systems Institute have been studying salmon and their stream habitats.

Debris flows are common events that can shape stream habitat in mountainous regions around the world, particularly in the rainy Pacific Northwest. “A landslide, once in a stream, can create a debris flow—a slurry of mud, rocks, and organic material that scours sediment and wood along steep headwater streams—and then deposit this downstream in lower gradient fish-bearing channels,” explains Burnett. “But, not all landslides enter streams and not all debris flows travel to streams containing fish.”

Debris flows are bad for fish—but that is only part of the story. The negative effects of debris flows can last from tens to hundreds of years, depending on the magnitude of the debris flow relative to the size of the stream. “Debris flows can be important sources of gravel, boulders, and large wood, which are fundamental components of habitat complexity for salmon. Forest management may alter many characteristics of debris flows, including how frequent they are, how big they are, how far they travel, and their composition” Burnett explains.

Scientists have come to understand, in the past few decades, the nuanced role that landslides and debris flows play in fish habitat development. Not all landslides

IN SUMMARY

Not all landslides are created equal. Some have the potential to run out to streams and others do not. Some are likely to simplify and damage stream habitat, and others can be important sources of gravel and large wood, fundamental components of habitat complexity for salmon and other stream inhabitants. Forest managers want to avoid negative consequences and promote positive characteristics of debris flows. Until recently, however, approaches to assess whether landslides will enter streams over large areas have been unavailable.

Scientists at the Pacific Northwest Research Station and their collaborators at Earth Systems Institute developed techniques to estimate densities of landslides over an entire region and specify confidence in those estimates. Landslide densities are estimated as a function of topography and forest cover from elevation data, forest mapping, and landslide inventories. Existing field- and air-photo-based landslide inventories are used together to capitalize on the strengths and overcome the deficiencies in each. For the first time, source areas for landslides can be differentiated between those likely and unlikely to affect streams. This can help decisionmakers more effectively regulate timber harvest and target forest management and restoration activities. Researchers also found that locations with the highest probabilities of initiating and delivering debris flows to fish-bearing streams can be managed by concentrating on a small percentage of the landscape.

KEY FINDINGS

- Debris flows can be important sources of gravel and large wood, which are fundamental components of habitat complexity for salmon and other stream inhabitants. Forest management may alter many characteristics of debris flows, including timing, magnitude, and composition, affecting stream organisms and habitats.
- Aerial photo inventories of landslide density have a bias toward detecting larger landslides and landslides in nonforested regions. Field-based inventories do not adequately estimate the variability over large areas. By combining the strengths of the two methods, researchers were able to estimate regionally accurate landslide density. They found landslide densities were lowest in older forests and highest in recently disturbed forests.
- Not all landslides are created equal, but approaches to assess regional differences have been unavailable. Researchers have recently developed a method to identify and rank source areas based on the potential to initiate landslides that can travel to and through a stream and thus affect fish habitat through scour or deposition.

are created equal, and scientists and land managers are developing ways to resolve which landslides are likely to influence streams and which characteristics determine whether the longer term net influence of debris flows on salmon and habitat is likely to be positive or negative.

“Large wood delivered by debris flows is a conspicuous component of stream habitat,” says Burnett. “The wood traps sediment and controls channel morphology.” Debris flows of trees and logs benefit fish habitat in the long run. In contrast, when a debris flow originates and travels through an unforested area, particularly one with little downed

wood from previous stands, it contains mostly sediment, and lacks a key structural element for long-term habitat complexity.”

The distinction between landslides on forested versus nonforested slopes is of particular concern in areas managed for timber production. “For several decades, controversy has swirled around the relationship between logging and landslide initiation in the Northwest,” explains Burnett. “And despite numerous studies, science has yet to completely resolve the debate.” Adding fuel to the controversy is the fact that previous studies have produced conflicting results about the role of forest cover on the probability of landslides.

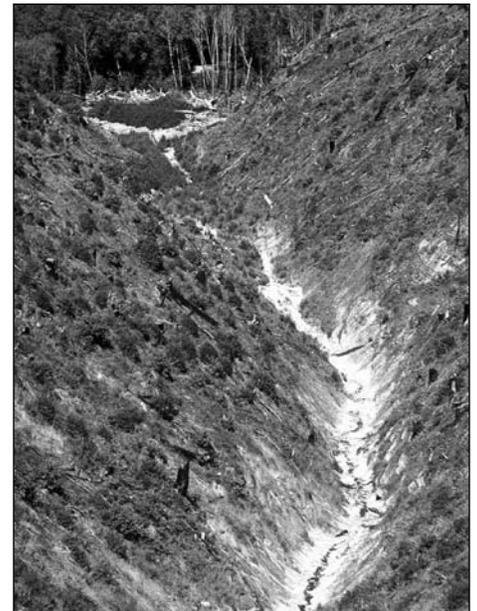
RESOLVING BIAS IN THE DATA: IT’S ABOUT SCALE

How could some studies show that landslides occur more frequently in logged forests, and other studies show the opposite? The answer to this riddle is found in the peculiarities of conducting landslide inventories, which typically come in one of two forms: aerial photos or field surveys. Both have inherent strengths and weaknesses.

“Landslide inventories from aerial photos have the advantage of looking across a broad area relatively inexpensively,” says Burnett. “The major downside is that the number of smaller landslides in mature forests tends to be underestimated from air photos because you can’t see smaller landslides through the canopy. As a result, regional estimates from air photos may be biased toward [detecting] more landslides in unforested areas.”

Although inventories from field surveys provide accurate measurements and counts of landslides in all forest age classes, field surveys can reasonably include only a small area, unless of course you have an army of surveyors. “Because of landslide patchiness—the simple fact that landslides tend to occur in clusters—landslide counts can vary considerably from one location to another even in forests of the same age,” says Burnett, “so, a field survey in a small area may miss general tendencies between forest age and landslide density that are applicable over a larger region.”

Working in the Oregon Coast Range, Miller and Burnett developed a technique that combines information from field and air photo landslide inventories to harness strengths in each.



There is a longstanding controversy regarding the relationship between logging and landsliding. New research shows that, after accounting for the patchiness of the process, there are lower landslide densities in older forests than in young forests or recently harvested forests.

Burnett and Miller created a technique to identify characteristics associated with land sliding and then used it to map likely landslide initiation sites across large landscapes. Their approach harnesses the advantages of traditional field-based estimates and combines them with aerial photography and computer modeling to understand some of the conflicting results in previous studies.

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“We estimated size distributions of landslides in a field inventory, used this to estimate the proportion of small landslides missed in an air photo inventory, then corrected for the bias in the air photo inventory to get a more realistic estimate of landslide potential in each forest age class,” Burnett says.

After correcting for bias, Miller and Burnett repeatedly subsampled the air photo inventory using sampling areas of different sizes and found that relative landslide densities measured over small areas often contradicted those measured over large areas. Many samples contained the highest landslide densities in

older forests when sample areas were small but not when sample areas were larger (at least 200 square miles). “If you look across an area large enough to account for patchiness in the process, then you can expect to see lower landslide densities in older forests than in young forests or recently harvested forests,” Burnett explains.

LOOKING FOR LANDSLIDES ACROSS LARGE AREAS

The fine-scale processes of landslides are well known, but few tools are available to predict both likely landslide initiation and travel paths over large areas. Burnett and Miller have been working to change this.

Landslides often start in steep hollows, areas where hill slopes converge and soil tends to accumulate. During heavy rains, water percolating through the soil can also concentrate in hollows to the point that the friction between bedrock, soil, and tree roots becomes insufficient to hold everything in place. Then, gravity takes over. Soil and vegetation travel downhill, snowballing with everything in the path until the slope flattens out or finds its way into a stream.

But topography is only part of the story; vegetation also influences where landslides initiate. As previously mentioned, landslides are less likely to begin in areas with mature forests. This may be because of deeper and more elaborate root networks, which help stabilize the soil. Recently cut-over or very young forests, in contrast, offer little root strength and, thus, can be more susceptible to sliding.

If a landslide enters a stream and creates a debris flow, then the distance it travels is all about gravity and friction. Debris flows pick up material through steep sections of stream and deposit this through lower gradient sections. Debris flows hang up at channel confluences. The angle, the gradient, and the valley

width at the junction determine the likelihood that the debris flow will pass through. Debris flows tend to travel further in recently harvested forests than in older forests.

“So, it’s a combination of several factors: the steepness of the terrain, the angle of the tributary junction, the size of the debris flow, the degree of channel confinement, and the amount of standing and downed trees that determine where a debris flow ends up,” Burnett explains.

Miller and Burnett have pioneered a method that effectively predicts landslide locations and their travel paths. Given digital maps of topography and vegetation across a landscape, they can identify hollows as sites that are likely to initiate a landslide. From there, the elevation and vegetation maps are used to predict the likely travel path of the slide downslope and downstream, creating what are called “runout probabilities” for the whole landscape. “For the first time over large areas, source areas for landslides that are likely to affect streams can be differentiated from those that are not,” says Burnett.



Landslides usually occur during heavy rains when the friction between bedrock, soil, and tree roots becomes insufficient to hold everything in place.

LANDSLIDES LINK HEADWATERS TO LARGER STREAMS

In headwater streams—those at the top of a watershed—debris flows generally scour the stream and do little to add complexity. This is because headwater streams are typically steep, and by definition, small. Therefore, most landslides simply overwhelm headwater streams. Some may not view this as a problem for fish habitat, because headwaters are often not fish-bearing. However, debris flows that start in headwater streams and travel to fish-bearing streams may scour or bury fish habitat, depending on characteristics of the debris flow and the

travel path. So, headwater and larger streams are often intimately linked by landslides and debris flows.

The approach developed by Burnett and Miller provides the capability to assess across an entire channel network whether debris flows are likely to scour or deposit in fish-bearing channels. “We can identify which hill slopes and headwater streams are likely to be sources of debris flows to fish-bearing streams and determine whether or not debris flows have the potential for a long-term positive impact,” explains Burnett. Not much

good can come from scouring fish habitat to bedrock, but where a debris flow deposits wood and boulders, it may ultimately contribute to increasing habitat complexity.

“The rankings of landslide initiation and runout probabilities we produce allow headwater streams to be prioritized as potential sources of debris-flow transported sediment and wood to larger streams lower in the watershed,” says Burnett.

NEW INFORMATION FOR POLICY AND MANAGEMENT

In the past, people thought that all debris flows were bad, that you never want landslides to initiate, and that nothing about the whole process was beneficial,” says Burnett. “However, we’ve realized that not all landslides have an equal potential to influence a fish-bearing stream. And, if debris flows do have an impact, the characteristics of the debris flow and the stream determine whether the long-term result is habitat degradation or delivery of new boulders, spawning gravels, and wood that in the future can contribute to habitat complexity.”

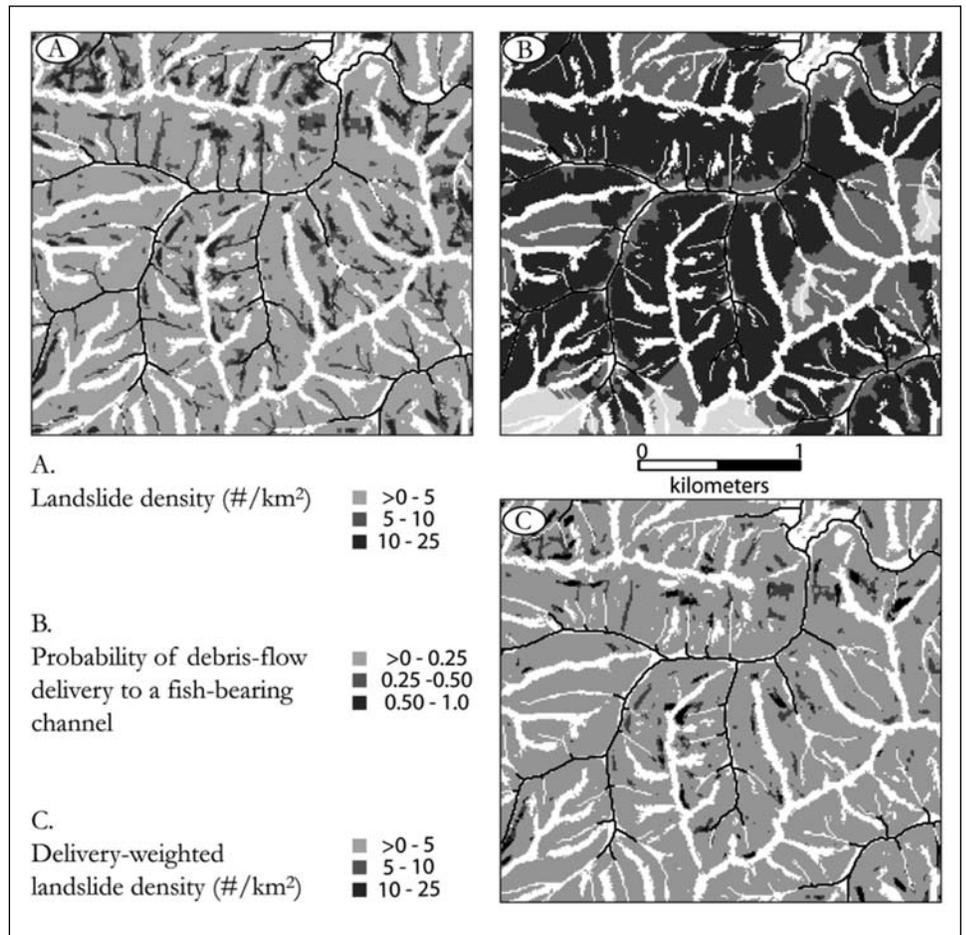
The work by Miller and Burnett will allow forest managers to make informed decisions regarding where logging may degrade stream habitat, and where it is unlikely to have a big effect. Specifically, the research findings rank hill slopes and headwater streams based on probabilities of initiating or being traversed by debris flows that deliver to a fish-bearing stream and then use the ranks to explore alternative streamside management zones.

“We found that locations with the highest probabilities of initiating and delivering debris flows to fish-bearing streams could be effectively managed by concentrating on a relatively small percentage of the landscape,” says Burnett. “This is a first, but important, step in illustrating how streamside protection may be tailored through considering the role of headwater channels in stream networks across a landscape.”

Policymakers and land managers may some day be interested in using an approach that considers probabilities of debris-flow initiation and runout in prioritizing headwater



In small, steep headwater streams, debris flows often overwhelm the stream basin and do little to add habitat complexity.



Researchers have developed techniques to rank hill slopes based on their probability of initiating debris flows that deliver wood and sediment to a fish-bearing stream. This tool is being used to explore alternative riparian management strategies.



LAND MANAGEMENT IMPLICATIONS



- New models that combine landslide initiation and runout probabilities offer an unprecedented opportunity to inform land-management decisions about landslide-associated risks to streams. For the first time, areas that are sources for landslides likely to affect streams can be differentiated from those that are not.
- By applying riparian protection along headwater streams with the highest probabilities of initiating and delivering debris flows to fish-bearing streams, forest managers can meet stream conservation goals for debris-flow-delivered wood concentrating on a relatively small percentage of the landscape.
- Capabilities to quantify ecologically relevant differences among headwater streams can aid in developing efficient and effective riparian management policies within the context of overall forest management goals.

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streams for riparian management. Effects would likely differ among classes of landowners and among individual landowners. For example, the area adjacent to headwater streams managed for riparian considerations may decrease in some locations on federal forests from that under the Northwest Forest Plan.

“Given that landslides are patchy, there could be a disproportionate economic effect of harvest restrictions on private owners of small parcels containing highly unstable ground, in comparison to landowners of large parcels or landowners of low-gradient land where there is little likelihood of a landslide. How you weigh and provide that equitably among landowners could become an important consideration for policymakers,” says Burnett.

Overall, Burnett thinks that this is an exciting time for integrating stream ecology into forest management, especially in headwater streams. “These areas gained notoriety after the Northwest Forest Plan extended riparian protection to intermittent streams based on emerging science that indicated their importance,” she says. “We’re now at a point where we can begin to synthesize 15 years of research on headwater channels, bringing together understanding about debris flows and the numerous other roles that headwater channels play in the larger stream ecosystem to find more effective and efficient approaches to landscape management.”

“Science is the knowledge of consequences, and dependence of one fact upon another.”

—Thomas Hobbes

FOR FURTHER READING

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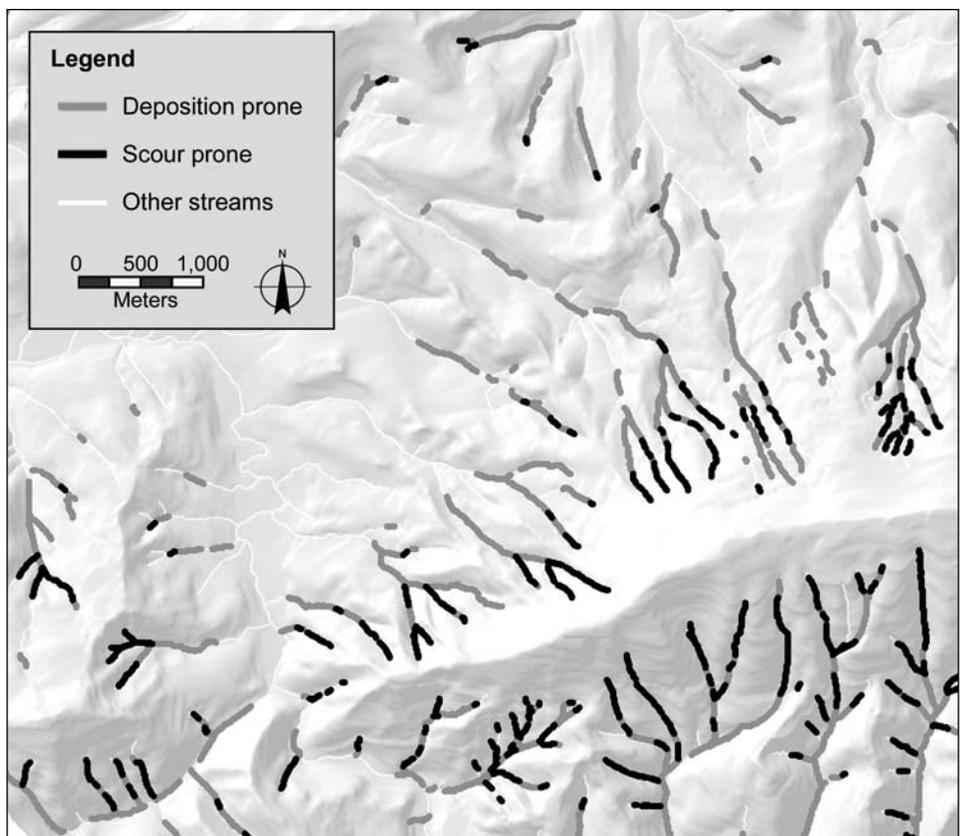
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In the short term, debris flows are bad for fish. However, they are one of the primary sources of wood, gravel, and other critical habitat components that are beneficial in the long run.



For the first time, forest managers have tools to distinguish the areas that are likely to initiate landslides that result in scour or deposition into fish-bearing streams from areas where slides will not affect streams at all. This technique will allow more effective and efficient management of forest and stream resources.



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