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FINDINGS

INSIDE

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"Science affects the way we think together."

Lewis Thomas

DOES WOOD SLOW DOWN "SLUDGE DRAGONS?" THE INTERACTION BETWEEN RIPARIAN ZONES AND DEBRIS FLOWS IN MOUNTAIN LANDSCAPES

In Japan, street signs warn residents when they are in the "runout zone" of a debris flow—translated literally from the Japanese characters as "sludge dragons."

IN SUMMARY

Conservation measures for aquatic species throughout the Pacific Northwest rely heavily on maintaining forested riparian zones. A key rationale for this strategy is that the presence of standing and downed trees next to streams will provide a continuous source of wood, which is an important structural component of aquatic habitat. Yet little is known about the interactions between wood and debris flows, which are an important way that wood enters streams.

Researchers from the PNW Research Station and Oregon State University created a physics-based simulation of debris flow dynamics in a headwater basin within the Oregon Coast Range. They found that the presence of wood fundamentally changes the behavior of debris flows by reducing the momentum and distance that they travel. Because debris flow deposits are primary storage sites for sediment within headwater catchments, a shift toward shorter flows means that more sediment is stored higher up in watersheds. In addition, they found that zones with high densities of wood and sediment are relatively fixed in space and do not migrate downstream. This suggests that management strategies could specifically target achieving habitat objectives within these high accumulation zones, and there may be multiple management pathways for achieving these objectives.

"Everything in nature contains all the power of nature."

—Ralph Waldo Emerson

Let's just get this out of the way right now: What on earth is a "sludge dragon?" If you have ever been to a mountain village in Japan, then you might have some idea. You would have seen the street signs depicting a menacing freight-train of earth with a dragon's head chasing villagers down a mountain, gobbling up homes along the way. The eye-catching signs are meant to warn people when they are in the potential run-out zone of dangerous debris flows or, translated literally from the Japanese characters, sludge dragons.

Gordon Grant, a research hydrologist at the Pacific Northwest Research Station in Corvallis, Oregon, likes the imagery of the term. He has researched landslides and debris flows in the mountains of Japan and throughout the Pacific Northwest. He knows in excruciating detail how much energy is represented by a landslide, and he knows when it is likely to morph into

KEY FINDINGS

- According to a physics-based simulation of debris flow dynamics in a small headwater basin in the Oregon Coast Range, the presence of wood adjacent to and stored within streams shortens the length that debris flows travel.
- Debris flow deposits provide the primary storage sites for sediment; a shift toward shorter lengths means that more sediment is stored higher up in watersheds.
- Large wood accumulations of wood in streams act as "valves," slowly releasing sediment over time. Where no wood is present, sediment travels much more rapidly to the mouths of watersheds with much less time spent as aquatic habitat along the way.
- The presence of wood in streams is a fundamental control on the long-term sediment dynamics and channel form in small headwater catchments. This is the first time that the presence of wood and its effects on debris flows has directly been tied to long-term erosion rates at the landscape scale.

Wood-fronted debris often scours stream channels. Photo: G. Grant.

an avalanche of earth, known as a debris flow. He has witnessed torrents of soil, rock, and water charging downslope, uprooting trees and everything thing in their path. So, to Grant, "sludge dragon" seems perfectly appropriate.

And, after all, geomorphologists already use terms like "snout" to describe the front, and "tail" to describe the back of debris flows—so what's the harm in adding another colorful descriptor to the nomenclature?

Grant spends much of his time trying to understand how water and earth intermingle. He is interested in why some hillslopes fail, whereas others are relatively stable. And, he tries to predict how far debris flows will travel once soil starts to move down a slope. It is the domain of fluid mechanics, flow dynamics, and mixture theory.

Much of Grant's research into the behavior of "sludge dragons" has been done in partnership with Stephen Lancaster, a professor in the Department of Geosciences at Oregon State University (OSU). Their most recent efforts have been focused on describing the role of wood in debris flows.

"Pacific Northwest rivers have all been shaped—either directly or indirectly—by landslides and debris flows. They leave an indelible mark on mountain landscapes," says Grant. "In fact, more than 30 years of research in the mountains of western Oregon points to the fact that forests, streams, and fish all co-evolved, with debris flows playing an important role linking these three elements together."

Debris flows travel downslope, often originating in steep headwater basins before moving into stream channels. As the debris flow accelerates, the largest boulders and logs are selectively shifted to the snout of the flow by internal forces, while the fast-moving slurry of water and mud pushes from the tail. At some point, after hundreds of feet or several miles, the flow loses energy, leaving a wake of scoured bedrock and a mass of boulders, soil, and trees piled at its terminus.

THE LINEAGE OF LOGJAMS

"Debris flows have typically been viewed as two-part mixtures of sediment and water, but in forested mountain landscapes, wood can represent a sizable fraction of the total flow volume," says OSU's Stephen Lancaster. "The effect of this third part on flow behavior is poorly understood."

For a long time, it was generally assumed that most logs in streams came from trees located on streambanks. Indeed, this is one of the rationales for retaining narrow riparian buffer strips after logging. However, over the past few years, a debate has been simmering in the scientific literature about whether the dominant source of wood is from stream-adjacent trees that simply fall in, or if trees far upslope are transported to channels via debris flows and then work their way through the stream network. Certainly, to some extent, both pathways are important and the effects of both processes need to be considered.

According to Grant, logjams in streams are a lasting and important legacy of debris flows. They are hotspots of aquatic habitat. The snarls of wood create complex hydraulic and physical architectures, which focus streamflows and scour the channel bed into deep pools. The logs are also dams. They trap sediment and gravel upstream. Leaves

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and branches get hung up and slowly leach nutrients into the water.

"Logjams create multilevel nooks and crannies, which are great fish habitat," says Grant. "Of course, they are more important in some streams than others; it depends on the amount of boulders and other structures. But wood introduces hydraulic complexity, and that's generally good for fish."

Large woody debris accumulations often stay in place for many decades, acting as "valves," slowly releasing sediment over time. Where no wood is present, sediment travels much more rapidly to the mouths of watersheds and spends much less time as fish habitat along the way. The retention of sediment is crucial to long-term success of spawning salmon and trout. It follows, therefore, that managers, charged with protecting endangered fish species, are concerned with the role of trees in debris flows, and where those debris flows occur in the watershed.

DEBRIS FLOW BEHAVIOR

"A lot of people are trying to get a better understanding of debris flows and streams in the Pacific Northwest. It is an important area of research," explains Grant. "In our work, we've been trying to ask questions in a slightly different way. It is a subtle but, I think, important distinction. Previously, the general perspective has been: We know that debris flows happen, so let's make sure the good stuff—the trees and other structures—is in place when they do. We take a slightly different view. We tend to think that the very nature of debris flows, how those flows happen, and what the behavior of the flows will be, depends on what stuff is on the slopes and in the channel."

In particular, Lancaster and Grant focus on wood as an influence on debris flow runout behavior.

Over many years spent looking at debris flows in the field, they had noticed that wood was often concentrated at the front of the deposit, with sediment trapped behind. They also noticed that logjams were usually located at bends in the channel and tributary junctions, where long logs become wedged in turns after colliding with valley walls. These observations led them to several research questions.

Does the presence of wood fundamentally change the behavior of debris flows—for example, how far they travel? Does the width or composition of the riparian zone affect debris flow dynamics? They used a small headwater basin—less than 1 square mile—in the Oregon Coast Range as their test subject.

"We developed a sophisticated computer model that couples storms, fire history, landsliding, debris flows, channel transport, and vegetation growth and decay," explains Lancaster. "One key component was a physics-based relationship that governs debris flow behavior due to a number of factors, including the amount of wood present in the stream system. Because of this component, the model can be used to directly explore how sensitive debris flows are to the presence or absence of wood."

"The topography of the basin in the Coast Range dictated the conditions at the starting gate," says Grant. "We then simulate the change in soil thickness, vegetation, and woody debris over time scales of many decades and centuries. During this period, fires occur randomly, killing vegetation, which reduces root strength. Eventually, there is a rain storm during which the cohesion that is holding the soil to the slope is exceeded and the slope fails as a landslide. From there, the model uses the fundamental laws of physics—the conservation of mass, momentum, and energy—to tell us how the debris flow would behave."

The physics-based portion of the model shows two primary ways wood reduces the velocity of debris flows. First, simply having to push wood along, as it is battered by the stream channel, reduces the total momentum of the flow. And second, changes in flow direction as the "sludge dragon" zigzags through mountain valleys cause wood to collide with basin walls, which absorbs some of the total energy, reducing the debris flow's speed.

Wood accumulating at the front of debris flows often becomes a sediment dam. Photo: G. Grant.

Big jams of wood within debris flows impound sediment, which is then slowly released into the stream over many years. Photo: S. Lancaster.

LOG LOADING AND RUNOUT LENGTHS

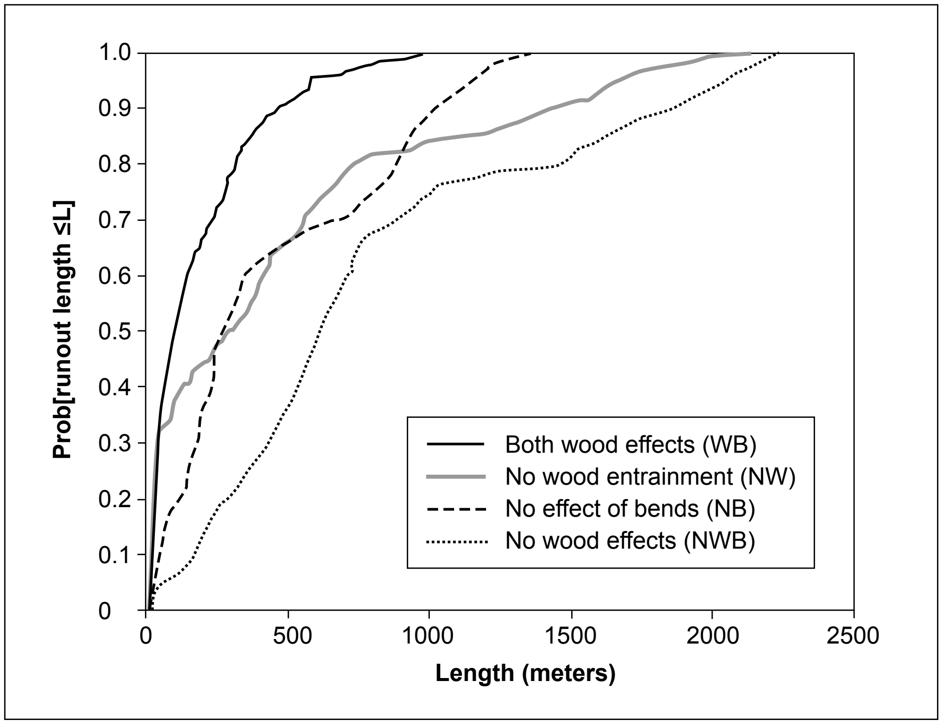
Grant and Lancaster's simulations were able to reasonably reproduce runout lengths of debris flows over a 40 year period. Of particular interest, the model demonstrated that the presence of wood adjacent to and stored within streams shortened the runout length of debris flows. In other words, debris flows that are charged with wood do not travel as far down the stream network.

The simulations indicate that wood-laden debris flows travel, on average, only one-fifth the distance of those without wood, and the maximum runout lengths are about half what they would be without wood. Those are big numbers with significant implications for sediment and fish and even for risks to people and infrastructure.

"Shortened runout lengths, in turn, dramatically affect the distribution of sediment stored within mountain catchments. Because debris flow deposits provide the primary storage sites for sediment within headwater streams, a shift toward shorter runout lengths means that basins with forested riparian zones are more likely to have sediment stored higher up in the watershed," explains Lancaster.

"This is the first time that the presence of wood and its effects on debris flows has directly been tied to long-term erosion rates at large spatial scales," he adds.

The question of how trees affect debris flows is more than academic. This becomes evident once you consider the prevalence of logging in mountainous landscapes, particularly within the Pacific Northwest.



Runout length distributions simulated by the physics-based debris flow model, with and without wood.

"There is a clear body of evidence that clearcut logging increases the likelihood of landslides. It has to do with the loss of root strength and consequent effects on slope stability," says Grant. "The effect of logging reducing slope stability is real, though it is less than some would guess. In steep, slide-prone terrain, logged slopes are, in general, about two to three times more likely to slide than unlogged slopes. Some forest roads, on the other hand, will increase the likelihood of landsliding by more than an order of magnitude."

The model that Lancaster and Grant constructed will be useful for land managers who want to consider previously untested ways of protecting aquatic habitat from the effects of logging.

MANAGING FOR HIGH-QUALITY DEBRIS FLOWS

There are two general approaches to managing riparian zones in the face of logging. The first is quite protective and applies on all federal lands governed by the Northwest Forest Plan. It calls for riparian reserves of 1-to-2 tree heights in width adjacent to virtually all watercourses and wetlands in forested terrain. Consequently, in areas with high stream densities, such as the Coast Range, virtually the entire landscape is in a riparian reserve. The other approach is typified by the Oregon State Forest Practice Rules, which govern timber harvests on private land and are less restrictive; these rules require smaller riparian buffer zones over a lesser extent of the stream network, usually permitting harvest within headwater basins.

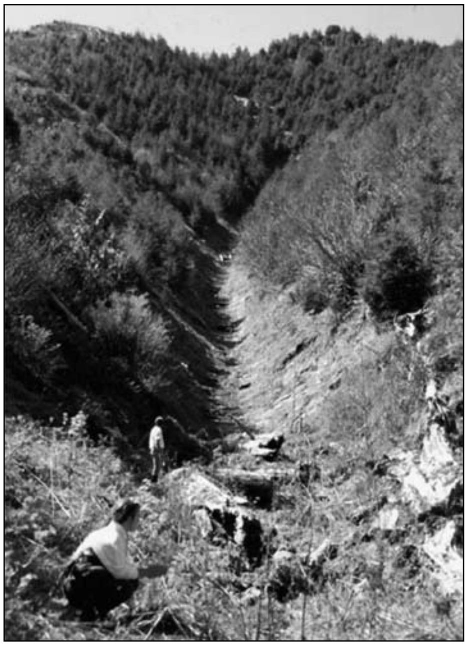
"There are few tools that permit managers to compare and contrast the effectiveness of these different riparian zone prescriptions," notes Grant. "Our model allows just that kind of comparison."

"The physics-based approach allows us to ask all sorts of questions about management strategies that have never been tried. We can ask: What if we only have riparian reserves on streams that drain to wood accumulation zones, or only on streams with high potential for landslides and debris flows? Presumably the laws of physics still apply, so the simulation should give accurate insights as to how processes would play out, even if these management strategies have never actually been implemented before" says Grant.

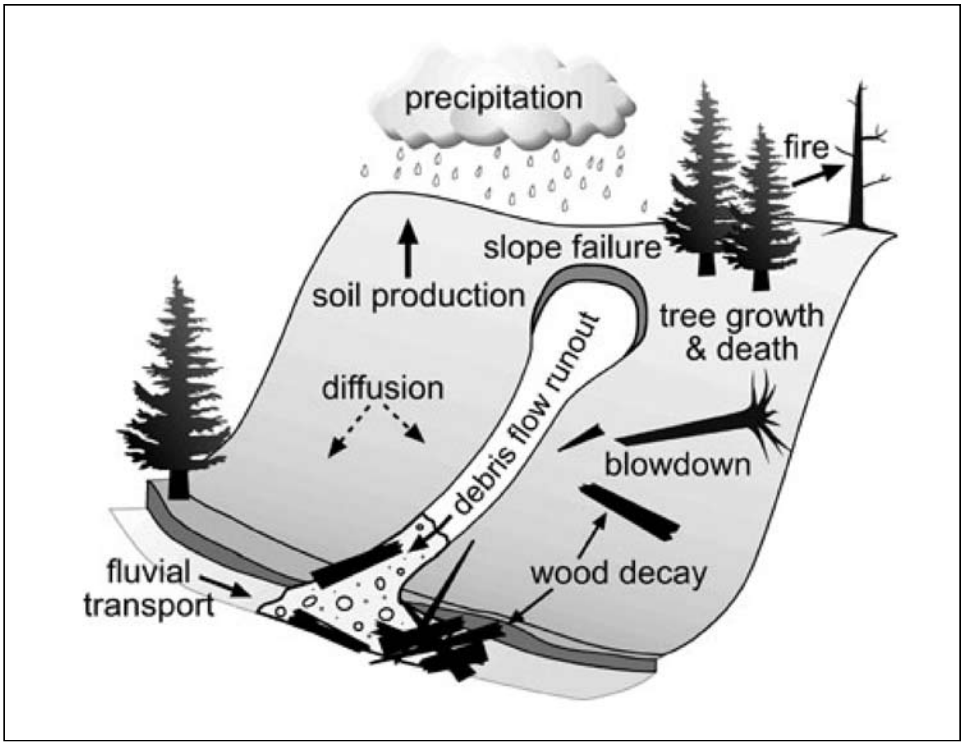
The model does not favor the federal or the state policies. Instead, results suggest that there is no one right approach to managing streams with respect to overall loading of stream systems with wood and sediment deemed important for aquatic habitat. In fact, it shows that there may be multiple strategies to achieve the same ends and that the best approach will be strongly dependent on the particulars of each watershed.

Like so many things in land management, a one-size-fits-all strategy will not be the best approach to meeting objectives. According to Grant and Lancaster, there may be a "tradeoff space" involving different lengths of the stream network in riparian reserves, different reserve widths, and possibly even different silvicultural practices within reserves. In addition, management activities could be specifically targeted toward the high accumulation zones, resulting in greater overall efficiency.

"This could provide much needed flexibility for managers seeking to achieve a balance



Boulder-fronted debris flow can persist in the channel for a long time after deposition, even after nearly all the wood has decayed. Photo: S. Hayes.



Many processes are involved in debris flows and must be incorporated into the simulation models.

among multiple objectives for forest and stream management," says Grant.

It should be interesting to see the expressions on the policymaker's faces when Grant explains the benefits of managing for high-quality sludge dragons.

> *"Those who dwell, as scientists or laymen, among the beauties and mysteries of the earth are never alone or weary of life."*
>
> —Rachel Carson

LAND MANAGEMENT IMPLICATIONS

- There may be multiple strategies to achieve the same ends with respect to overall loading of wood and sediment within stream systems, which has been deemed important for aquatic habitat. This analysis suggests that using different lengths of the stream in riparian reserves, different reserve widths, and possibly even different silvicultural practices within reserves all may be useful ways of meeting objectives, depending on the stream network under consideration.

- Zones with high densities of wood and sediment are relatively fixed, and do not migrate downstream. This suggests that management activities could be specifically targeted toward these high accumulation zones, resulting in greater overall efficiency.

FOR FURTHER READING

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