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Rocks, Paper, Soils, Trees: The View from an Experimental Forest

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Erika, a scientist who had built a career on studies of the northern spotted owl, silently surveyed a tall, old-growth forest in the Oregon Cascade Mountains. This cold, rainy, winter's day in 1999 fueled reflections on her studies here as a graduate student in the 1970s, when the owl was the subject of no more than minor academic interest. In the intervening two decades, this owl species had become central to an environmental war over the balance of wood production and protection of remaining old-growth forests. In a series of legal skirmishes, the timber cut on the vast area of federal lands in the region was reduced to a small fraction of levels cut in the 1980s. Extensive reserve systems were established to protect the owl and hundreds of other species. Coming from a family of loggers, the many dimensions of this battle—overly simplified as “owl versus jobs”—have a very personal impact on Erika. She is well aware that each participant in the battle has distinctive answers to the questions, “What is a forest? How should it be managed?”

Today Erika has come back to this experimental forest to think about an issue that is very old. Recent flooding renewed centuries-long debate about effects of forest cutting and roads on the magnitude of these floods and the amount of sediment in drinking water. But recent social and scientific developments frame this old issue in a more complex manner than ever before: How should we manage dynamic forest ecosystems and watersheds to sustain high-quality drinking water, as well as protect habitat of native species and provide wood fiber for our use? As in the “owl wars,” scientists have been asked to present results of their studies, particularly findings from highly interdisciplinary work in experimental forests, such as this. Why do we care about the health of forests and well-functioning watersheds?

As so many people are aware now—especially in the Pacific Northwest—forests are a nexus of interactions among earth, water, atmosphere, and human society. Healthy forests supply wood products but may also provide important ecological services. They regulate stream flow and water quality, offer homes to innumerable organisms of known and undiscovered values, and even influence global climate. Forests constitute an enormous reserve of carbon on our planet. Trees and other vegetation in forests take in carbon dioxide from the atmosphere and give off oxygen. The fixed carbon may be stored for long periods of time in plant matter or soil, before decomposition or fire releases it to circulate once again through the atmosphere or hydrosphere. When we cut forests, we remove from the earth system functioning organisms that can mitigate global warming caused by excessive amounts of carbon dioxide and other gases in the atmosphere.

Interactions of forests with the hydrosphere and the Earth's soil and near-surface bedrock are multifold. Forests pump liquid water from the soil and exhale it to the atmosphere as water vapor. In some environments, trees capture fine water droplets from passing fog and clouds, bringing nearly three feet of water to sites that would not receive this moisture without them. Forest vegetation tightly regulates the flow of chemical elements from precipitation or from breakdown of underlying bedrock. In steep, mountainous areas, forests blanket the soil with a thick, protective layer of organic litter. Tree root systems anchor the soil in place, reducing the potential for landslides. The rate of soil erosion by landslides and water runoff can increase following soil disturbance from logging and other land uses, giving testimony to the watershed protection services provided by intact forests. Water quality in downstream areas can be degraded, if erosion rates exceed normal levels. Much of the nation's drinking water comes from streams and rivers draining forested headwaters, so we have good reason to maintain healthy forests.

Our appreciation of the roles of forests in this intricate web of interactions has evolved slowly.¹ In the Pacific Northwest of the nineteenth century, forests stood in the way of progress. Over much of the twentieth century, forests represented planks waiting to be made into houses and other structures. Foresters and scientists working for the U.S. Forest Service, industry, and universities wanted simply to maximize production of wood. Several developments in the late twentieth century set the stage for dramatic change in our relationship with forests of this region. Environmental concern grew, represented in part by landmarks such as Earth Day and passage of the Endangered Species Act. At the same time, geologists and biologists worked together to gain a broader and deeper comprehension of how ecosystems and watersheds function. These important studies took place in a small number of sites across the country where interdisciplinary groups conducted long-term research that has profoundly influenced land use policy.

The H. J. Andrews Experimental Forest in the Cascade Mountains of Oregon is one of these special sites. The 16,000-acre Andrews Forest is

characteristic of old-growth conifer forests, steep hillsides, and cold, clear streams of the Cascades. Here long-term ecosystem research has allowed earth scientists to detect, define, and resolve important environmental problems; it has provided technical guidance for development of sustainable approaches to management of forests, streams, and watersheds. Research at the Andrews Forest is done by geologists, ecologists, and their students who share a strong commitment to learning about this compelling landscape. Some of these scientists work for the U.S. Forest Service in its Pacific Northwest Research Station, and others work for Oregon State University as well as other educational institutions. Working closely with land managers of the Willamette National Forest, scientists translate research findings into new approaches to sustainable land use. The long-term ecosystem research conducted at the Andrews Forest, in which I participate, excellently displays the roles of earth sciences in forest ecosystem research—the subject of this essay.

Since its designation as an experimental forest in 1948, the Andrews has been home to hundreds of studies of hydrology, ecology, and forest geomorphology—examination of the Earth's surface forms and the processes that sculpt them. These investigations occupy the realms of both basic science and science applied to natural resource management. Of course, the Andrews Forest is not the only one of its kind in the United States. We are fortunate to have a national network of similar long-term ecosystem research sites, that helps us to understand better the interactions of geology and ecology in a variety of ecosystems, ranging from Arctic tundra and Antarctic dry valleys to the urban ecosystems of Baltimore and Phoenix. Hubbard Brook and Luquillo Experimental Forests in New Hampshire and Puerto Rico, respectively, are examples of other forested sites like Andrews among the 21 Long-Term Ecological Research (LTER) sites that the National Science Foundation funds. Additionally, there is an international network of LTER-like sites and a UNESCO-sponsored network of Biosphere Reserves, which collectively provide examples of the major ecosystems of our planet. Scientists from around the globe jointly conduct studies across sites within these networks, and their interdisciplinary, socially relevant work contributes to broad application of scientific results.

The earth sciences began to take a prominent role in ecosystem research at Andrews Forest during experimental watershed studies initiated in the 1950s. In these studies, hydrologists and soil scientists teamed with ecologists studying plant communities and nutrient cycling to examine effects of forest cutting and road construction on stream flow, water quality, and soil erosion. This work on areas of forest that ranged in size from 25 to 250 acres examined short-term effects as they occurred in the watershed. However, the accumulated information now spans more than 40 years.

My own involvement began in 1972 when I mapped the geology of the Andrews Forest as part of an international effort to understand the workings of the major types of terrestrial ecosystems of the globe. I was eager to take part in

interdisciplinary studies with colleagues in ecology. It is unfortunate, but not surprising, that the time scales we were interested in did not match; the youngest rocks I was mapping were 3.5 million years old—geologically young—but the ecologists were studying biological processes that operated at time steps from minutes to, at most, a few years. With the luxury of time to work together, however, we gradually developed overlapping time and space scales of shared interest. We found common ground in our forest as we tried to understand how ecosystems operate over large areas, on the order of more than 10,000 acres, and over long periods of times, many centuries. Such large areas and swatches of time encompass major wildfires, windstorms, landslides, and floods, all of which have profound effects on ecosystems and hydrologic systems. The long-lived conifer trees record in their growth rings a 500- to 1000-year history of forest development as well as the effects of these kinds of catastrophic disturbances. Also, these great spans of space and time are very relevant for examining the effects of forest land use on soil productivity, biological diversity, and watershed conditions.

I and my colleagues from the U.S. Geological Survey and the U.S. Forest Service developed the study of forest geomorphology. That is, we were interested in landforms as the physical stage on which forest and associated stream ecosystems operate, and we looked at geomorphic processes as agents of ecological change and of movement of soil sediment and nutrients through the forest and streams. We were strongly influenced by the fascinating work that John Hack, a noted geomorphologist with the U.S. Geological Survey, and John Goodlett, who had extensive experience studying forest-soil relations in New England, conducted in the Appalachian Mountains.² Working together, they found that soil and vegetation differ greatly between stream bottoms and ridges and that a major downpour dramatically disturbed streamside vegetation, even in this geologically stable Appalachian landscape. As geologists, we were excited at the prospect of working in the steep, wet, geologically unstable, heavily forested landscapes of the Pacific Northwest, which are part of the tectonically active Pacific Rim. To our minds, the themes of forest geomorphology pioneered by Hack and Goodlett would be even more dramatically expressed here.

Research at the Andrews Forest over the past three decades has followed several lines of development in forest geomorphology, each of which has led us to appreciate the dynamic character of forest and stream ecosystems. Some key pieces of this story include investigations of how soil and sediment move through watersheds³ and roles of vegetation and land use in controlling this movement,⁴ especially during floods.⁵ The links between geological and ecological worlds are built on knowledge of the interactions between forests and streams⁶—particularly the effects of woody debris in stream systems,⁷ and the influences of land surface form on ecological processes.⁸ All this work has had tremendous implications for the management of these ecosystems and watersheds.⁹ Let me sketch some examples.

Geologists who study forest geomorphology have adopted the systems-oriented thinking of scientists who study hydrology and nutrient cycling in order to characterize the movement and storage of soil and sediment, including organic matter, through watersheds. This work, termed sediment budget and routing studies, seeks to document the amount, types, and paths of sediment moving through a particular watershed and the relative contributions of various geological processes to the total amount of sediment coming from that watershed. In the realm of forest geomorphology, an important question concerns the distinctive effects of vegetation on paths of soil and sediment as they travel through a watershed. For example, strong tree roots can minimize small landslides, wind-toppling of trees can trigger soil movement by turning up root systems, and logjams can store sediment and thereby affect water quality in downstream areas.

These studies have revealed new lessons about natural and managed watersheds. Past ecological studies of the cycling of soil and nutrients through watersheds have focused on the subtle, daily removal of elements dissolved in stream water. However, geological studies of sediment budgets show that the convulsive movement of soil and sediment by landslides, although previously missing from ecological analyses, is a major way that materials are removed from forested ecosystems in steep, slide-prone landscapes. Removal of forest cover can increase landslide frequency for a decade or two, as well as increase the rates of other erosion processes. And landslides do more than transport soil and sediment; they severely disturb plants, animals, and their habitat.

If the only aim of watershed managers was to ease the passage of water and sediment through stream systems, their job would be simple. Today, management of watersheds and ecosystems demands that we find useful balances between geological and ecological worlds, and between simplicity and complexity. The history of work on coarse woody debris in forested streams illustrates the challenge of finding a good balance. In the early years of research on the Andrews Forest ecosystem, geomorphologists and stream ecologists examined effects of coarse woody debris on sediment routing, stream channel shape, and aquatic habitat. Previous investigators had ignored big wood in streams for the simple reason that it was inconvenient to study. That is, big wood decomposes very slowly and moves infrequently. In fact, on the time scale of a typical research grant or thesis project, a large, dead tree changes very little.

By the mid-1970s, however, the geomorphic, ecological, and land management issues surrounding woody debris in streams of the Pacific Northwest demanded attention. At that time, a debate raged over leaving wood in streams or taking it out, and there was little distinction between natural wood and wood derived from logging operations. Up until the 1960s, loggers left large amounts of logging debris in streams. Generally small pieces, this material was highly mobile in floods and could worsen damage to bridges, buildings, and streamside vegetation during floods. Fisheries biologists were concerned that

tight-knit logjams composed of logging debris could block passage of migrating fish, like salmon. So wood in streams got a bad name. But studies in natural stream systems of the Andrews Forest gave a different picture. Undisturbed, forested streams commonly contained a wide size-range of woody debris—from the very small to massive logs that were less likely to be carried away by high water flow during storms. Investigators observed fish swimming upstream around or through the natural, loose-knit, logjams during periods of high water flow. In fact, the habitat complexity created by logs in streams continues to provide refuge for fish and other organisms during floods.¹⁰ Woody debris in streams also traps sediment, slowing its movement downstream and providing diverse habitats, including spawning beds for fish.

These findings helped us realize that, in forested areas, we must keep *logging* debris out of streams, maintain *natural* woody debris, and manage streamside regions to provide a continuous supply of woody debris with a natural size distribution. As a result of this research, it is now common practice to design streamside forest zones based on future wood supply to the streams. It is also considered good practice to place woody debris in streams to restore habitat complexity where natural levels of woody debris have been reduced by flooding or removal of fallen logs and standing trees.

As with any theme addressed through long-term research, our thinking about dynamics and functions of woody debris in streams and studies of those functions have evolved over time. This evolution has occurred through both gradual accumulation of knowledge, such as lessons from annual tracking of over 2000 numbered logs in study streams, and in the rush of learning that occurs during a major flood event as we watch 100-foot-long logs float down a stream for the first time in careers that span more than two decades. Because of these observations, we have begun to study mobile wood, its styles of transport, and its effects on streamside vegetation. Floating wood can topple streamside vegetation when carried along on a swift current, bumping into standing trees. So, while big wood in streams has many obvious ecological benefits, it is also an agent of disturbance.

Disturbance is not a common term in the language of geomorphology, but it is widely used in ecology. Perhaps life scientists recognize disturbances because processes like landslides can destroy the subject a life scientist studies. To a geologist, however, a landform-producing process is not viewed as a disturbance. In part, as a result of the involvement of geologists in ecosystem research in recent decades, all scientists more fully appreciate the beneficial aspects of disturbance processes. Many species depend on disturbance events to help them regenerate. Seed dispersal, germination, creation of seedbeds and light conditions favorable for growth are all made possible by disturbances that change the form of the landscape; fire and severe wind in upland habitats and floods and landslides passing through stream networks create landscapes that constitute a shifting mosaic of areas in various stages of recovery after disturbance events.

Understanding the natural disturbance regime of a landscape—the frequency, severity, and spatial patterns of disturbance—is a critical ingredient in appreciating the structure and function of both native and managed ecosystems. The types, ages, and arrangements of plant communities, for example, tell us when and where disturbances have previously occurred in the forest. Also, different types of forest management alter the disturbance regime of a landscape. Intensive plantation forestry and fire suppression, for example, change the frequency, severity, spatial pattern, and type of disturbances that might occur. Forests once prone to fire—ironically a rejuvenating event for some forests—may become crowded, ill, and subject to disease when fire is excluded. Clearly, disturbance processes are integral components of ecosystems.

Scientists and land managers at the Andrews Forest have noted this and have developed landscape management plans based on appreciation of the historical disturbance regimes and range of ecosystem conditions in forests.¹¹ For example, geological information tells us which areas of the forest are highly susceptible to landslides.¹² As a result, we can avoid human aggravation of naturally unstable areas, and allow natural processes, such as the movement of large woody debris to streams by landsliding, to proceed. We can use information about forest fire history to determine which portion of a forest to leave on a site and which portion to remove for wood products. Thus, we distribute our own disturbances across the landscape in a conscientious manner. This approach complements the conservation biology approach to landscape management, which is based solely on the habitat and dispersal needs of selected species. Science-based management can blend these perspectives on the biosphere, near-surface sediment and rocks, and hydrosphere with a firm grounding in the history of the landscape. Currently we are testing this new, geologically aware approach that uses historical disturbance regime information in a 55,000-acre “adaptive management” area in the hopes that it will enable us to manage better our forests and watersheds.

These sketches about development of concepts and information about sediment paths and budgets, woody debris in streams, and disturbance regimes in landscapes show the results of creative, interdisciplinary research on forest ecosystems and watersheds that includes the critical knowledge of earth science. Earth scientists in particular bring to these studies long-term historical perspective and familiarity with large spatial scales. These perspectives are essential for dealing with today's difficult natural resource issues.

In over a quarter-century of work at the Andrews Forest, I have learned some useful lessons about long-term ecosystem research and its value to society. First, scientists, land managers, policymakers, and the public have essential and distinctive roles in deciding how we will manage our nation's forests and watersheds. Second, it is difficult to anticipate which scientific findings will have great social impact. The work on old-growth forests and northern spotted owls at the Andrews Forest in the 1970s was considered by some to be

esoteric and therefore of no societal value. Yet a decade later, this research contributed to major shifts in our perceptions of the nation's forest resources and effected changes in how we manage this resource. Our views of these regional and national changes have been shaped strongly by hundreds of field trips to the Andrews Forest, where examples of basic research and alternative land management systems are discussed critically with people who hold very different perspectives on these management issues. And, scientists have done more than simply publish scientific papers on this issue in peer-reviewed journals; a key paper on the nature of old-growth forests published in the so-called gray literature as a Forest Service General Technical Report¹³ was intellectually accessible to anyone interested in the story.

In research at the Andrews Forest, it has been important to balance persistence in sustained long-term studies with attention to major science and societal issues of the day. Good, long-term data are extremely valuable and can be used to address new questions with new techniques. But, frequently it is also important to reevaluate and prove the relevance of such long-term studies to current issues. Well-targeted, short-term studies can help build the link between information in long-term data sets and current questions. Over the course of 40 years of study in the experimental watershed, for example, concerns have shifted successively from the effects of forest cutting on drinking water quality to soil erosion, flooding, and low stream flows as they affect species habitat. Once again, there is great concern about drinking water quality after a major flood in 1996 triggered high turbidity levels. The growing record of watershed conditions and performance over time has allowed us to address old questions with an expanded data record and to ask new questions, such as, How do revegetation patterns affect watershed hydrology and water quality? The answers are complex; but in the simplest terms, a healthy forest, even one establishing itself just a few decades after severe disturbance, can substantially limit the magnitude of floods and soil erosion.

Scientific work at the H. J. Andrews Experimental Forest has been exciting and rewarding in itself, but the sense of accomplishment has been magnified greatly by realizing that discoveries there have helped society better understand these ecosystems and watersheds, which it so enjoys and on which it depends. Geology, although it encompasses vast scales of time and space, contributes perspective and knowledge relevant to our most current issues and sets the historical foundation for practicing good care and stewardship of the natural world.

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Maintaining a Livable Planet



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