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INSIDE

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"Science affects the way we think together."
Lewis Thomas

LIFE ON THE EDGE: CARBON FLUXES FROM WETLAND TO OCEAN ALONG ALASKA'S COASTAL TEMPERATE RAIN FOREST

Rick Edwards

Dissolved organic carbon flushed from the soil of Alaska's coastal temperate rain forest stimulates a food web that supports the state's fishing industry. Climate changes projected over the next 80 years could change the fate of soil carbon, triggering changes in linked aquatic and marine ecosystems.

"Rain! whose soft architectural hands have power to cut stones, and chisel to shapes of grandeur the very mountains."
—Henry Ward Beecher

The North American coastal temperate rain forest runs from western coastal Alaska to northern California. It's known for heavy rainfall, lush vegetation, mountains that practically stand in the ocean, and estuaries that teem with life. The Tongass National Forest lies within this biome and in some places receives up to 200 inches of annual precipitation, which drains from the forest into the thousands of small streams along the coastline. Given the steep topography, these streams are short—often traveling less than 3 miles before they empty into coastal estuaries. The nutrients these streams deliver stimulate a food web that supports Alaska's $5 billion fishing industry. This highly productive mix of fresh and saltwater appears bright green on satellite imagery, extending 600 miles into the gulf.

The near constant flushing of freshwater over and through the mosaic of forest and peatland soils into headwater streams intimately connects the terrestrial and aquatic systems of the coastal temperate rain forest. Rick Edwards, a research aquatic ecologist, and Dave D'Amore, a research soil scientist, both with the Pacific Northwest Research Station in Juneau, Alaska, have studied these interactions, rate of carbon flux, and implications for forest and carbon management in the context of climate change for the last 5 years. In doing so, they've made

IN SUMMARY

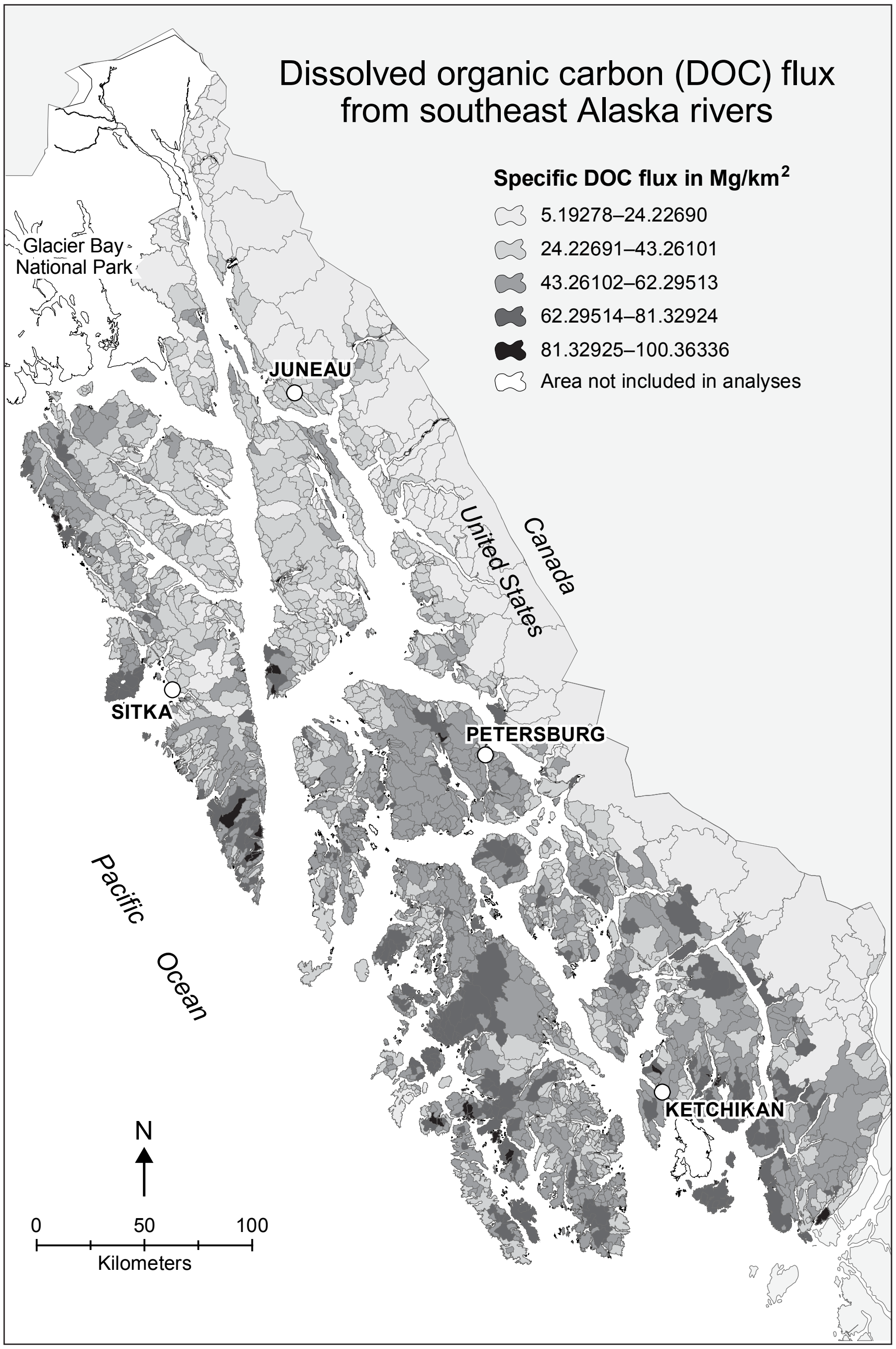
Acre for acre, streams of the coastal temperate rain forest along the Gulf of Alaska export 36 times as much dissolved organic carbon as the world average. Rain and snow are the great connectors, tightly linking aquatic and terrestrial systems of this region. The freshwater that flushes over and through the forest floor leaches carbon and other nutrients from the soil and delivers them to headwater streams. Dissolved organic carbon derived from soils has a large biodegradable component, making it an important food source for freshwater and marine food webs. In the Tongass National Forest alone, there are 14,000 streams exporting these high-value nutrients to the estuaries that support Alaska's $5 billion fishing industry.

Climate-induced changes to the amount, timing, and type of exported dissolved organic carbon could have far-reaching impacts on estuarine productivity and habitat quality. Scientists Rick Edwards and Dave D'Amore with the Pacific Northwest Research Station are studying these connections. This research, coupled with adaptive management applications, will provide information on the short- and long-term aspects of carbon cycling on the Tongass National Forest. This information can then be applied to regional and national carbon accounting goals.

some discoveries that have changed the fundamental conversation about nutrient cycling and carbon management in the coastal temperate rain forest.

The Tongass National Forest contains 8 percent of all carbon stored in U.S. forests. Two-thirds of the Tongass carbon is stored in the soil. Because of all the rain, carbon is constantly moving from soil to water as one component of dissolved organic matter. "From the soil, carbon can move in different pathways," explains Edwards. "Understanding these pathways provides the basis for managing forests to increase carbon storage."

Before Edwards and D'Amore began this research, little attention had been given to carbon flux within Alaska's coastal region. "Southeast Alaska doesn't have a single, large charismatic river like the Yukon [which flows through interior Alaska and empties into the Bering Sea] where a lot of research was going on, or the Mississippi," explains Edwards. Conventional wisdom said the coastal temperate rain forest had relatively



The discharge of dissolved organic carbon in streams in southeast Alaska is the highest reported in the world, per unit area. One megagram (Mg) equals 1 metric ton.

KEY FINDINGS

- The carbon flux from the coastal temperate rain forest along the Gulf of Alaska is exceptionally high. Acre for acre, the watersheds of the gulf coast export 36 times as much dissolved organic carbon (DOC) as the world average, suggesting that the fate of carbon in this ecosystem influences regional and global carbon cycles.
- Dissolved organic carbon derived from soils has a large biodegradable component, making it an important food source for freshwater and marine food webs. As it moves through aquatic ecosystems, the nonbiodegradable fraction of the DOC is sequestered within sediments and suspended in the ocean DOC pool rather than being released into the atmosphere.
- A new analytical tool provides a shortcut for assessing the quality of DOC in terms of its digestibility. This novel method led to the surprising discovery that peatlands (muskegs) generate DOC that is high in protein and readily digestible by stream and estuarine organisms.
- The quality of dissolved organic material as a food source varies by wetland type, and the amount and composition of carbon within a wetland changes seasonally.
- Soil carbon pools are sensitive to environmental variables that are projected to change over the next 80 years. These changes could dramatically change the fate of sequestered soil carbon, which could lead to changes in the aquatic systems of southeast Alaska. These changes could also lead to increases in carbon returned to the atmosphere rather than stored belowground or in the ocean.

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small carbon flux because it was assumed most of the carbon was stored in trees and thus relatively inert.

The researchers challenged this notion. They found that a vast pool of carbon is stored belowground in the coastal temperate rain forest and that a large lateral flux exists between the soil carbon pool and streams. Compared to the Yukon River, the streams of the Tongass National Forest discharge 20 times as much dissolved organic carbon per unit area, and 3 times as much as the Amazon.

These findings raise the question: why do the streams of the coastal temperate rain forest export so much carbon? Part of the answer likely lies in the length of the waterways. In contrast to the short, steep streams along the Gulf of Alaska, in the Yukon and Amazon basins, water travels hundreds or even thousands of miles, during which time the carbon in it has more opportunity to be retained by organisms before it reaches the ocean.

Another part of the answer points to the tightly connected aquatic and terrestrial systems in the coastal temperate rain forest and decomposition rates slowed by cool temperatures and wet soils.

LINKING SOIL AND WATER

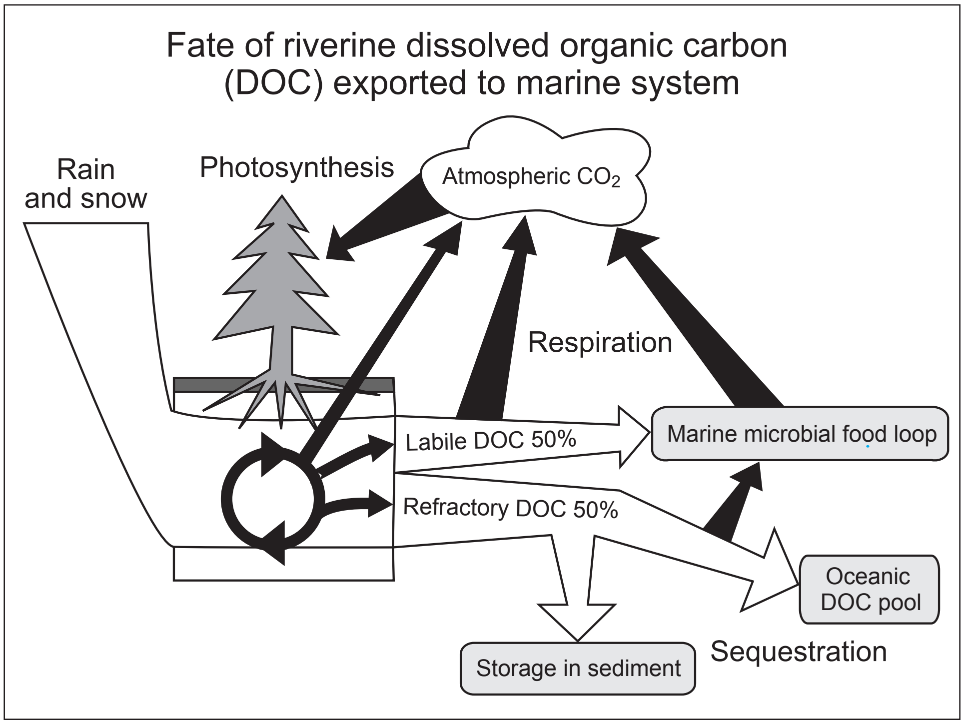
"Traditionally soil has been looked at as a medium for growing plants, and soil science focused on how nutrients derived from soil cycle to the plants and back to the soil," says D'Amore. "When Rick and I started working together, we asked, 'What about the interaction of these soils not only with plants but the flow of nutrients though soil water and into streams?' We've been able to link the soil chemistry to the hydrology of soils and see that they play a major functional role in the movement and storage of nutrients, which serves as an important nexus between plants and streams."

"It was generally accepted that the things leaving soil were used up, inert," D'Amore continues. "Why would anything useable be exported? It would definitely be used by the soil microbes and trees. We challenged that paradigm and found that the soils of the terrestrial systems can be rich sources of useful material for streams."

Soil has two basic components: decomposed rocks and decomposed plant parts. The dissolved organic matter (DOM) is smaller than minute decayed plant parts. It includes carbon, which can be measured, along with other elements that can't yet be measured. Dissolved organic material can be further distinguished as either edible (labile is the scientific term) or inedible (refractory) to microorganisms, such as soil bacteria, and fungi.

"The refractory DOM has already been chewed on, so to speak, by soil microbes and so is chemically more inert and not used as much," explains Edwards. "If you think of DOM as a steak, the labile portion is the meat and fat, the refractory is the gristle and bone."

"As the carbon moves from soil to streams, there's a series of interactions specific to different soil types," says Edwards. "The whole process is microbially mediated. Microbes turn the edible carbon into food for organisms like stone flies, salamanders, and ultimately fish. The headwater streams in the Tongass are heterotrophic—the food they need to support the food web in the stream comes largely from outside the boundaries of the stream."



Once flushed from the soil to the stream, the biodegradable components of dissolved organic carbon (DOC) and other organic matter (DOM) are consumed by aquatic and marine organisms, whereas the nonbiodegradable components are eventually sequestered in sediment or the ocean.

FINDING THE SOURCE

Before questions about manipulating the forest system to achieve desired results can be addressed, the basic workings of the unmanaged system need to be understood. "Dave and I try to figure out what regulates the influx of nutrients. We walk in the woods and carve the watershed into distinct associations of plant and soil that can tell us something about how the watershed works," says Edwards.

"Once you understand how a soil has formed through geological processes, vegetation, time, and weather, then you can put that in context and start arranging the landscape through soil maps," explains D'Amore. "By understanding the functional attributes of soil, you can assume that these soil types are going to have a distinct signature in terms of the quantity and quality of the DOM they yield."

Jason Fellman, a graduate student at the time, worked with Edwards and D'Amore to develop and use a new method for quickly and inexpensively assessing the quality of dissolved organic matter. "PARAFAC [parallel factor analysis] is really a shortcut to other more expensive, time-consuming methods," says D'Amore. PARAFAC allowed the scientists to validate their hypothesis that certain soils yield different amounts of dissolved organic

Rick Edwards

Researchers collect soil samples from a peatland (muskeg) in southeast Alaska. This study led to the discovery that peatlands are an important source of high-quality dissolved organic matter that is readily digested by microorganisms.

Rick Edwards

Researchers found that the form of carbon in streams changes seasonally.

Rick Edwards

Changes in the timing of water movement through the soil and into rivers and ocean will affect the timing, amount, and type of nutrients reaching aquatic and marine food webs.

matter with varying rates of edible and inedible material. It also led to the surprising discovery that peatlands, commonly thought to produce poor-quality DOM, in fact generate DOM that is high in protein and readily digestible by microorganisms. They also found that the contribution of labile organic material to streams varies by soil type, and the form of carbon found in streams changes seasonally.

"We can use this information to develop a better model that allows us to anticipate how different watersheds may behave in the future under different temperature and moisture scenarios," says Edwards. He continues, "We won't have a chance to mitigate climate change if we don't have the fundamental knowledge to predict how things might change. And, if we want to be able to anticipate where the forest is going under different climate scenarios, we can't just look at the trees."

A MOVING TARGET

The climate over the past 14,000 years is the key reason so much carbon is stored in the soil in southeast Alaska: it's cool and wet. "Decomposition rates are slower under cooler temperatures and water-logged soils," explains Edwards. "The best examples are peatlands where carbon has been building up since the end of the last ice age. They've been sequestering carbon for thousands of years, but because it's so wet, some of the carbon is constantly being flushed by rain into the streams." As the researchers have found, this amount is significant—36 times greater than the world average, per unit area.

If temperature and precipitation patterns change as projected over the next 80 years, the carbon flux will likely change as well. The big question is how? "Climate models predict wetter weather in southeast Alaska, so more carbon could be stored in the soil if this slows decomposition rates further," says Edwards. "But temperature increases are also predicted, which could lead to increased evapotranspiration by trees, and thus drier soils. In the United Kingdom, where scientists have been studying this for 60 years, they're seeing a lot of carbon that was stored in peatland is now mobilized in water, or being used in respiration so it is released as gas into the atmosphere."

"When we get warm summer weather, soil organic material decomposes and flows out of the soil after the next heavy rainfall. When these warm-wet cycles alternate over the course of the growing season, a large quantity of soil carbon can be exported from the soil, especially in forested wetlands. If these warm-wet cycles occur more frequently than they do now, they will have a big impact on the soil carbon cycle, and the net sequestration capacity of these forests," D'Amore explains.

WRITER'S PROFILE

Rhonda Mazza is a science writer with the Pacific Northwest Research Station in Portland, Oregon.

And because stream productivity in southeast Alaska is directly linked to the nutrient inputs from the forest, changes to the soil carbon cycle will likely affect aquatic systems. Changes in freshwater habitat from increased mobilization of DOM, along with increased water temperatures and higher stream respiration rates could negatively affect survival of salmon during egg development and early juvenile stages. "As snow lines move up the mountains and watersheds change from ice- and snow-dominated discharge patterns to rain-dominated, the timing of water movement through the soils and into rivers and ocean will change," explains Edwards. The consequent changes in the timing, amount, and type of DOM reaching the aquatic food webs could have far-reaching impacts on their productivity.

MOVING TOWARD CARBON OFFSETS

Despite its high carbon flux, the coastal temperate rain forest is a huge "sink," storing large amounts of carbon in trees and soil. The stability, or steady-state condition between inputs and outputs, of the terrestrial carbon cycle can make it very difficult to increase net carbon storage in an existing forest through management. Likewise, estimating the net amount of carbon sequestered in a forest system over time is difficult because the net change in carbon within the system is a very small fraction of the large pools of carbon stored in the vegetation and soil. As a result, discussion about mitigating climate change through forest management in southeast Alaska is shifting from carbon sequestration to carbon offsets.

Rick Edwards

A researcher collects water samples to test the amount and type of dissolved organic carbon present.

Carbon offsets help resolve the conundrum created by the fact that management activities release stored carbon. The goal becomes offsetting those emissions by using forest-based biomass, for example, to replace fossil fuels. A carbon offset strategy "means you can still harvest or thin trees and then regenerate the stand and accumulate carbon in biomass while using the harvested forest products," explains D'Amore. "The net emission of carbon to the atmosphere is closer to neutral due to the substitution of biomass for fossil fuel."

Federal forests are managed for many goals other than carbon sequestration, Edwards points out. "If the bigger system is a vast carbon sink, the loss of carbon through management activities may be small in comparison. We just need to reconcile the carbon balance," he says. And to do this, requires understanding how that bigger system works.

"Within the Tongass National Forest there are approximately 600,000 acres of second growth and nearly 16 million acres of unharvested native forest, peatlands, alpine summits, and glaciers," D'Amore says. "What's going on under natural conditions may be more important in terms of overall ecosystem function than the managed portion of the landscape. We have to understand the functions of the entire landscape and reconcile the interaction of functions between the mosaic of harvested and unharvested areas."

"Changes in the unharvested component may be much greater that anything done in the managed stands under conditions of dramatic climate shifts," D'Amore continues. "Aboveground biomass manipulations may be complicated by unexpected trajectories in soil decomposition and loss of carbon through respiration and dissolved organic carbon. Therefore, we need to understand what's happening ecologically across the entire landscape for perspective regarding our actions."

"The soil is the great connector of our lives, the source and destination of all."

—Wendell Berry

LAND MANAGEMENT IMPLICATIONS

- Carbon sequestration is a priority in climate-change mitigation efforts. In southeast Alaska, researchers have quantified several components of the carbon cycle in soils and vegetation, and included the dissolved carbon pool to estimate carbon sequestration rates in the coastal temperate rain forest. This research, coupled with adaptive management applications, will provide information on the short- and long-term aspects of carbon cycling on the Tongass National Forest. This information can then be applied to regional and national carbon accounting goals.

- The high value of carbon and other nutrients exported to coastal estuaries suggests that climate-induced changes to the amount and type of exported material could have far-reaching impacts on estuarine productivity and habitat quality. Changes in the timing of water movement through the soils and into the rivers and oceans will alter the amount of dissolved organic carbon available to food webs or entering longer term storage pools.

- Changes in freshwater fish habitat stemming from increased mobilization of dissolved organic carbon, increased water temperatures, and higher stream respiration rates could negatively affect survival of salmon during egg development and early juvenile stages.

FOR FURTHER READING

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RICK EDWARDS is a research aquatic ecologist with the Pacific Northwest Research Station's Juneau Forestry Sciences Laboratory. His primary research interests are nutrient cycling, stream productivity, hyporheic ecology and carbon cycling in rain forest watersheds. He has worked in blackwater rivers in south Georgia, the wettest areas of the driest continent (Australia), and now works in the wettest area of the United States. A pervasive theme of his research has been carbon export in wetland-dominated streams and the utilization of carbon by stream biota.

DAVE D'AMORE is a research soil scientist with the Pacific Northwest Research Station's Juneau Forestry Sciences Laboratory. He has conducted forest ecosystem research in southeast Alaska since 1994 that has focused on the interaction of soil hydrology and biogeochemistry on terrestrial and aquatic systems. His current research is examining how soil geomorphology influences forest and peatland carbon cycling and storage in the coastal temperate rain forest.

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