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INSIDE

Science FINDINGS

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

Counting Carbon: Calculating How Headwater Streams Contribute to the Carbon Cycle

Rhonda Mazza

Researcher Alba Argerich collects a water sample in the H.J. Andrews Experimental Forest, Oregon, as part of a study that measured instream carbon concentrations. Calculating the carbon budget for a watershed involves determining how much carbon is stored long term in trees and how much cycles through and out of the watershed.

IN SUMMARY

The forested watersheds of the Pacific Northwest can sequester a significant amount of atmospheric carbon dioxide (CO_2), making them valuable carbon sinks for offsetting the carbon emissions that are contributing to global changes in the climate. However, as trees are storing carbon, water is leaching it from the soil. Some of the carbon is captured by microbial communities living in the stream's hyporheic zone, a region within the streambed, where it is turned back into CO_2. Gas exchanges between water and air release this CO_2 back into the atmosphere. These carbon fluxes previously have not been well quantified, which could affect carbon budgets developed for national forests.

Researchers with the U.S. Forest Service Pacific Northwest Research Station and Oregon State University analyzed 10 years of data from a headwater stream located in the H.J. Andrews Experimental Forest in western Oregon to calculate the watershed's annual carbon budget. They measured the concentrations of dissolved organic carbon, dissolved inorganic carbon, and particulate organic carbon in the stream and hyporheic zone and estimated the CO_2 flux from the stream surface.

Their calculations revealed that the watershed annually exported 6 percent of the estimated amount of carbon sequestered by the forest, or 33,476 lbs, equal to the carbon contained in 32 cords of wood.

"And liquid Lapse of murmuring Streams…"
–John Milton, poet

Pacific Northwest forests play a significant role in the global carbon cycle. Because they sequester atmospheric carbon, they are considered long-term carbon sinks when one is calculating the carbon budget for the region. Yet a forested landscape is more than trees; numerous headwater streams are tucked within the landscape. As these headwater streams transport water downstream, carbon hitches a ride.

This carbon is derived from a number of sources. When leaf litter rots in the stream, carbon is released. Fish and other organisms living in the stream respire carbon dioxide (CO_2), and even microbial communities buried beneath the streambanks respire carbon as a byproduct of their metabolism. The amount of carbon exported by these sources, however, is largely unknown. Compared to larger rivers, few data are available on headwater streams and their role in cycling carbon.

"We usually neglect headwater streams because the amount of water they have is so tiny, but they are numerous," explains Alba Argerich, an assistant professor with the

University of Missouri who specializes in stream ecology. "They cover a huge portion of our landscape."

According to Argerich, headwater streams comprise up to 90 percent of the total length of stream channels of watersheds, globally. This means that headwater streams have a direct impact upon the global carbon cycle, and this includes the carbon budgets of national forests.

To fulfill the requirements of the 2012 Forest Service Planning Rule, which requires the agency to mitigate and adapt to climate change, management practices could be designed to increase the amount of carbon stored on national forests. However, if the streams on national forests are exporting carbon, then the amount of carbon the forest is sequestering could be overestimated. And until recently, it was unknown just how much carbon was being exported from these headwater streams.

While a postdoctoral researcher at Oregon State University, Argerich worked with Sherri Johnson, a research ecologist with the USDA Forest Service Pacific Northwest Research Station, to study the metabolism of a headwater stream located in the H.J. Andrews Experimental Forest on the west side of the Cascade Range in Oregon. The way that inputs such as leaves (organic carbon) are used by a forested aquatic system is very similar to the metabolism of a living organism. Organic carbon, derived from leaves and needles dropping from overhead trees, is a source of fuel for a stream's microbial community. As the microorganisms digest this carbon, they produce CO_2 as a byproduct.

Over the course of their stream metabolism research, Johnson says that she and Argerich realized that another, much larger question was being overlooked—the carbon budget of the stream. "There was growing interest in sequestering carbon in forests, but nobody was really thinking about the role of streams in exporting the multiple forms of carbon," she says.

KEY FINDINGS

- A 10-year detailed carbon budget of a headwater stream in the H. J. Andrews Experimental Forest found that the stream annually exported 142 pounds (lbs) of carbon (C) per acre (142 lbs C/ac/yr) or a total of 33,476 lbs, equal to the carbon contained in 32 cords of wood.
- The annual rate of carbon exported from this small stream was similar to the average exported from much larger rivers around the world. However, this amount is a small proportion (6 percent) of the terrestrial net ecosystem productivity of this forested watershed (2,210 lbs C/ac/yr), owing to the high productivity of forests in the Pacific Northwest.
- The subsurface area of the streambed, known as the hyporheic zone, was a source of dissolved inorganic carbon to the stream and contributed 24 percent of the total carbon exported (34 lbs C/ac/yr). Most of the dissolved inorganic carbon released into the stream was a byproduct of microbes consuming buried particulate organic matter in the hyporheic zone.
- Both the stream and its hyporheic zone were always supersaturated with carbon dioxide (CO_2) compared to CO_2 in the atmosphere, which has currently about 400 parts per million (ppm). Stream levels of CO_2 (470 to 3,350 ppm) were 18 to 738 percent greater than in the atmosphere, while the hyporheic zone CO_2 levels (3,500 to 15,000 ppm) were 775 to 3,650 percent greater than in the atmosphere.

Steve Wondzell

Graduate students Rob Pennington (left) and Jason Brandes install new wells that tap into the hyporheic zone of a stream in the H.J. Andrews Experimental Forest.

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Calculating the carbon budget of the stream required Argerich and Johnson to better understand the stream's carbon cycle. In 2009, they began collecting new stream chemistry data to complement existing monitoring of basic stream chemistry that started in 2002 in this small watershed. They placed new sensors in the stream to measure concentrations of dissolved oxygen and CO_2 and evaluated water samples in the laboratory for concentrations of dissolved organic carbon, dissolved inorganic carbon, and suspended particulate carbon. (Dissolved organic carbon originates from organic matter, whereas dissolved inorganic carbon comes from inorganic sources such as CO_2 and carbonic acid).

To fully evaluate the stream's role in the carbon cycle, they needed to know how much carbon escaped from the stream's surface into the atmosphere. "Because you don't see this gas exchange happening, you forget about it, but it's happening all the time," Johnson says. To do this, they added short-term tracers to the stream water to measure how long it took water to move down the stream channel and to measure gas exchange rates between the stream and the atmosphere. They also deployed sensors to measure CO_2 concentrations at 15-minute intervals, 1 inch above the stream surface, from July 2012 to February 2014. However, even with these detailed measurements, only the aboveground portion of the stream's carbon cycle was being quantified. Missing was how much dissolved carbon was entering the stream from underground.

Nick Dosch

Graduate student Hayley Corson-Rikert uses a small well to collect water samples from the hyporheic zone. These samples were used to calculate the amount of CO_2 being generated by the microbial community in the sediment.

Collaborating to Collect Carbon

Steve Wondzell has spent his career as a research ecologist with the Pacific Northwest Research Station learning more about the hidden hyporheic zone. "The hyporheic zone is a place where stream water flows through the streambed and into the gravels and sands that surround the stream," explains Wondzell. "This water travels in the streambed for some distance before coming back to the stream. It's a strange source of groundwater because it comes from the stream."

The ecosystem of the hyporheic zone rivals that of the riparian zone, its aboveground counterpart. "The amount of life occurring in the hyporheic zone, which includes bacteria and fungi, but also insects and other arthropods, is tremendous," he says. Bacteria and fungi colonize the surface area of every grain of sand and decompose the organic matter buried within the sediment. This decomposition releases CO_2, which is picked up by the water as it slowly passes through the sediment. The CO_2 has now become a carbon input to the stream.

In 1996, Wondzell installed a well network along a segment of a headwater stream to sample water from the hyporheic zone. Coincidently, this same headwater stream was later selected by Argerich and Johnson as the site for their stream metabolism research. After realizing they had related studies based in the same small watershed, "we decided to work together to get the whole picture," Argerich recalls.

"A lot of papers would speculate that these subsurface processes are important [in the carbon cycle], but they seldom have been directly measured," Wondzell says. "This was an opportunity to combine these two viewpoints—surface and subsurface."

Graduate students under the direction of Wondzell and Roy Haggerty, a professor at Oregon State University, collected 18 months of water samples from the stream and well network. The amount of dissolved organic and inorganic carbon levels were measured in each sample, and these data helped fill in a big missing piece of the carbon cycle.

Calculating the Carbon Budget

With aboveground and belowground data in hand, the group analyzed the datasets to create an annual carbon budget for the headwater stream in this 236-acre watershed.

Their analysis revealed that the headwater stream exported 142 lbs/ac/yr, an amount similar to the carbon exported to the ocean by larger rivers such as the Mississippi River. The annual export by this tiny stream is nearly 33,476 lbs of carbon, equivalent to the carbon in 32 cords of air-dried wood. This total represents roughly 6 percent of the estimated 2,210 lbs/ac/yr sequestered by the surrounding forest, which is commonly referred to as the net ecosystem productivity of the watershed.

"I was amazed by how much carbon was being exported by this stream," Argerich says, "It's a tiny stream, and in the summer, it almost dries up."

Of the 33,476 lbs of carbon exported downstream each year, most of it is exported as dissolved inorganic carbon in the stream water. The second largest export is CO_2 gas that excapes the stream surface directly to the atmosphere. The remaining stream exports are composed of particulate organic carbon and dissolved organic carbon. According to Wondzell, the hyporheic zone is the primary driver behind the 8,885 lbs of carbon that escape into the atmosphere in the form of CO_2. "The processes that are going on in the hyporheic zone are taking the stream water and adding so much CO_2 to it that it becomes supersaturated," he explains. "Then when that water comes back into the channel, the CO_2 escapes into the atmosphere as the stream water tries to re-equilibrate to the atmospheric conditions."

"We were surprised that the stream was so super-saturated with CO_2," Johnson adds. Stream levels of CO_2 (470 to 3,350 ppm) were 18 to 738 percent greater than the atmosphere (about 400 ppm), while in the hyporheic zone, CO_2 levels (3,500 to 15,000 ppm) were 775 to 3,650 percent greater than in the atmosphere.

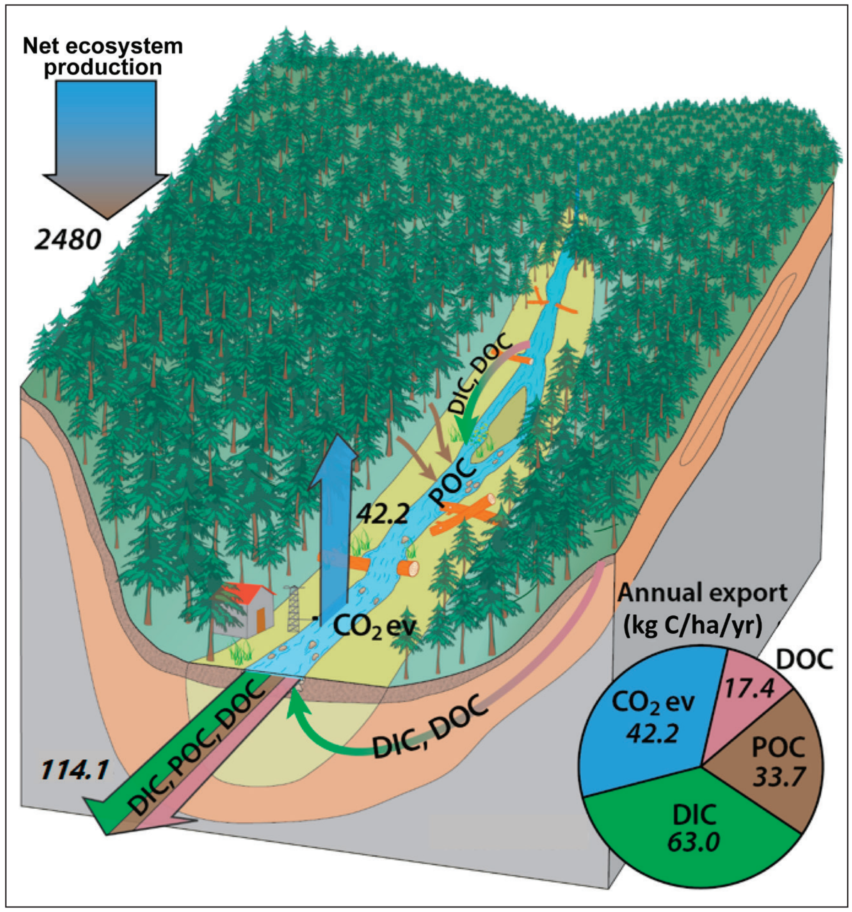
The research also revealed that seasonal dynamics and the amount of streamflow influence the carbon budget. "The time of the year determines how much carbon is being exported, as well as its form," Argerich explains. Ninety percent of the annual carbon export occurred between November to April, which coincided with high streamflows. Dissolved organic carbon fluxes were high following the first fall rainstorm and then declined during the winter.

One Carbon Question Answered, More Remain

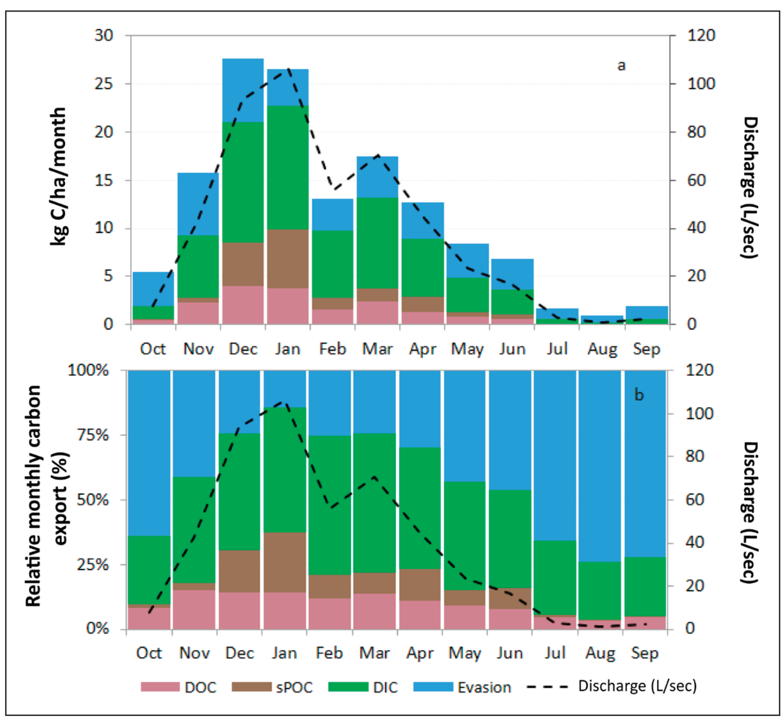
This collaboration has resulted in one of the first stream carbon budget studies in the Pacific Northwest, but both Argerich and Wondzell say more work is needed to reduce the uncertainties of how carbon cycles through a stream and its hyporheic zone. "The papers that have been published on our work are not the end of this particular journey," explains Wondzell. "They're just a couple milestones along the way and the work continues with lots of questions about how all these pieces fit together."

In spite of the outstanding questions, their work has immediate value toward informing management activities.

"Managers are interested in understanding how stream processes will contribute to the overall and long-term health of streams, and our research helps builds their understanding of the hyporheic zone," Wondzell explains, adding that managers are now asking how management activities such as stream restoration



Carbon (C) moves through a watershed in various forms. Trees capture carbon dioxide (CO_2) from the atmosphere and produce particulate organic carbon (POC) in the form of leaves, stems, and roots. Particulate organic carbon may break down to become dissolved organic carbon (DOC), or microbial communities transform it into dissolved inorganic carbon (DIC), which after entering the stream may either escape into the atmosphere (CO_2 evaded) or remain as dissolved inorganic carbon and be transported downstream.



The export of carbon (C) is affected by streamflow and seasonal dynamics. The greatest amounts of carbon leaves the stream in winter as a result of high streamflows. The first fall rains flush out organic matter that accumulates over the summer, resulting in high levels of dissolved organic carbon leaving the system.

projects can enhance this part of the stream. One example of how the hyporheic zone plays a role in stream health is that it helps regulate stream water temperature; during the summer, the water flowing out of the zone cools the headwater streams during the daytime.

Above ground, by including carbon exports of headwater streams, forest ecosystem models can better account for how much carbon is being sequestered by the forest and what is exported from the streams, says Argerich. "This information can be used to build more accurate climate models, which in turn, will give us better predictions of future temperature."

Although the calculated carbon export values are specific to one watershed in the H.J. Andrews Experimental Forest, Johnson says the numbers are applicable to other conifer-dominated watersheds in the Pacific Northwest. "Researchers and policy folks are starting to look at carbon and thinking about the role of rivers and streams in carbon budgets, but they've been focusing on very large and coarse scales, such as annual estimates on the Mississippi or the Amazon," she says. "Being able to work at a small watershed scale has allowed us to fine-tune our understanding of the seasonal dynamics of a carbon budget in a forested watershed."

Another success of the study that Argerich is quick to emphasize is the collaboration that made this study possible. "We looked at the carbon budget question from different angles: hydrology, stream ecology, and atmospheric science. By working together, this is how we move science forward."

"The flow of the river is ceaseless and its water is never the same. The bubbles that float in the pools, now vanishing, now forming, are not of long duration."
–Kamo no Chōmei, author and poet

LAND MANAGEMENT IMPLICATIONS

- The role of forests as carbon sinks may be overestimated if aquatic carbon exports are not taken into account. When developing a carbon budget for a national forest in the Pacific Northwest, including the amount of carbon being exported by streams is crucial.
- Terrestrial sources of organic carbon are the primary energy source to heavily shaded, forested headwater streams. Understanding carbon inputs helps understand patterns of stream ecosystem productivity.
- This research further underscores the importance of the hyporheic zone in stream ecosystem process and emphasizes the importance of maintaining or restoring hyporheic functions in streams through forests.

Steve Wondzell

This watershed in the H.J. Andrews Experimental Forest annually exports 6 percent of the estimated amount of carbon sequestered by the forest.

Further Reading

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