Peter Pollard paddles along the Brisbane River to sample viral and bacterial numbers.

The Missing Carbon Link

BY PETER POLLARD

The amount of CO_2 that plants take out of the atmosphere during photosynthesis is not matched by what is returned. Could microbes in our rivers be the missing link?

Rising carbon dioxide levels in the atmosphere are a great concern for our continuing existence on Earth. Our climate is changing because we are increasing the rate that CO_2 enters the atmosphere, and we are doing this faster than the rate at which it is naturally removed.

Generally, rainforests are viewed as storehouses of greenhouse gases. However, evidence is building that we may not have the climate change "get-out-of-jail-free" card that we would like.

In the global carbon cycle, plants use sunlight and photosynthesis to take CO_2 out of the atmosphere to make plant material. Ultimately the plant material is returned to the atmosphere through plant, animal and microbial respiration.

Every time you exhale you are returning to the atmosphere the CO_2 that a plant removed from the air using the Sun's energy. So, the Caesar salad you had for lunch or the meat you ate for last night's dinner was from cattle that had grazed on plants or fish that had eaten algae in the ocean.

While this cycle is commonly understood, the amount of CO_2 returned to the atmosphere via microbial respiration in aquatic environments has been largely overlooked. People tend to think of microbes (bacteria and viruses) as germs that make them ill, but in reality these bad guys are the minority. Most microbes are essential for our survival on planet Earth because they recycle nutrients, including CO_2, through land, water and air.

Typically, water quality assessments rarely take into account bacterial and viral dynamics, yet they are the ultimate controllers of aquatic ecosystem health. In my work as a microbial ecologist I study the interaction of algae, cyanobacteria ("blue-green" algae), bacteria and viruses in water and look at how carbon and CO_2 is cycled. My interest lies in the measurement of microbial production and respiration in freshwater ecosystems in the subtropics of south-east Queensland.

During 2000 and 2001 I conducted a 12-month study of the ecosystem processes in the Bremer River in south-east Queensland, which enters the Brisbane River 80 km upstream of Moreton Bay. The aim was to follow carbon movement through the microbes in the river ecosystem to see how they behaved in relation to the amount of organic matter they used and the amount of CO_2 they generated during respiration.

Bacteria in rivers and lakes use dissolved organic carbon (DOC) in river water as food. Individually, bacteria are small but what they might lack in size is made up for many times over by their enormous numbers and by how fast they grow. In the Bremer River I found 100 million viruses and 10 million bacteria in every millilitre of water, with the bacterial populations doubling every 30 minutes.

Peter Pollard treks through rainforest in Panama to test whether microbial respiration in rivers could be the missing link in the carbon cycle.

The pool of DOC in the Bremer River provided nutrients for the bacteria, and the concentrations remained relatively constant between 5 and 7 mg Carbon/L (17 gC/m^2). These concentrations are often seen in other river systems, so this was not unusual. However, the bacteria were eating this DOC food at a rate of 7.7 $gC/m^2/day$, and that was faster than rates we see in sewage treatment plants in Queensland. Of this, 4.5 $gC/m^2/day$ was going into bacterial body mass while the remaining 3 $gC/m^2/day$ was lost through bacterial respiration as CO_2.

We examined the number of bacteria and viruses on a 17 km reach of the Bremer between its junction with the Brisbane River and close to the Amberley Air Base near Ipswich. We noticed that the number of bacteria did not change much along the river, nor did we see a change in these bacterial numbers over the time of the study.

The concentration of DOC in the water column also remained stable during the study. This told us that the bacteria in the water were replaced each day by a new crop. This demonstrated that there was a continuous supply of food (DOC) that was being used by the bacteria, so there was a continual removal of the bacteria from the ecosystem.

These rates of change were phenomenal and suggested something was removing the bacteria from the system at a rapid rate. But what was the source of the dissolved organic carbon pool driving the high rates of bacterial growth? Why and how could it turn over so rapidly? How could the bacteria be dying as fast as they were growing?

Algae in the river generated DOC from photosynthesis, which helped provide bacteria with energy and carbon for growth. However, the results showed that the algal production was not sufficient to support the very high rates of bacterial growth that we observed in the river.

On a daily basis, the amount of DOC needed to support bacterial production could not have come from the algae alone (1.1 $gC/m^2/day$) as bacterial net production was at least four times greater than the algae could provide. There were other major sources of organic carbon into the river driving the high rates of bacterial growth and respiration, but they were not immediately obvious. Even in the dry winter months, with little rainfall run-off, bacterial production remained high, suggesting there were major and continuous sources of DOC coming into the river and the existence of a mechanism for the rapid removal of bacteria, possibly through viral infection and the death of the bacteria.

Viruses are obligate parasites. They consist of a piece of DNA or RNA wrapped in a protein coat. They are not living organisms as they need a host cell to replicate. They attach to their host, in our case bacteria, and inject their DNA via a tail. Once inside, the viral DNA is substituted into the replicating processes of the host bacterium, making as many as 50 copies of the virus per cell.

Once viral assembly is complete the bacterium dies and the virus causes the bacterial membrane to rupture. The new viruses are released along with the bacterial cell's contents into the surrounding environment to provide more food for the neighbouring bacteria.

As soon as the new virus makes contact with another bacterium, the attachment, infection and lysis cycle starts again. Each pass of the lytic cycle adds to the size of the DOC pool, which in turn stimulates more bacterial growth and respiration.

In the Bremer River the 10 million bacteria in each millilitre of water were replicating every 30 minutes, yet the bacterial numbers did not change dramatically because the viral populations were keeping them in check. Viruses lysed the bacteria, and the resulting DOC was then used by other bacteria that were further lysed to generate more DOC, and the bacterial–viral cycle was perpetuated with a constant supply of DOC.

Ultimately, in each pass of the cycle, DOC was respired to the atmosphere as CO_2. Bacterial production was not passed up the food chain to higher trophic groups like fish.

Terrestrial plant production is a likely major source of DOC in the aquatic environments of sub-tropical Queensland. Rapid bacterial and viral cycling of river-dissolved organic carbon ensure that the bulk of the DOC entering the rivers is returned to the atmosphere as CO_2 as rapidly as it enters the aquatic ecosystem. The end result is that all the organic carbon that enters the rivers is rapidly and efficiently turned into the greenhouse gas carbon dioxide.

This project suggests that bacteria in our rivers are generating half a tonne of CO_2 for every kilometre of river per day. The bacteria are using plant material as food and the oxygen in the water to breathe and generate CO_2 during respiration. It is very feasible that these freshwater microbial processes may be important in closing the global carbon cycle as they return to the atmosphere huge amounts of CO_2 originating from the land.

Meanwhile, on the other side of the world, scientists at the Smithsonian Tropical Research Institute in Panama are trying to balance the amount of CO_2 that rainforest plants take up during photosynthesis with the amount returned to the atmosphere during plant respiration and the decay of the plant material in the soil. Essentially, a rainforest (like other ecosystems) has a carbon "budget" – an equation that determines how much carbon dioxide is produced and how much is fixed back into the Earth through carbon "sinks" such as trees and vegetation during photosynthesis.

The Smithsonian scientists are finding that there is a huge shortfall in the amount of CO_2 returned. No one knows how this CO_2 is returned to the atmosphere. Are rainforests really sinks of atmospheric CO_2 or is there a more subtle return pathway to the atmosphere through the bacterial–viral loop in the nearby river ecosystem?

The mystery is that these numbers don't quite add up – it's almost as if there is a line item on this balance sheet missing. The amount of CO_2 that plants take out of the atmosphere during photosynthesis is not matched by what is returned. There's obviously a source of carbon dioxide that we haven't found yet.

The imbalance may worsen as global destruction of rainforests continues. We know that deforestation contributes to climate change by removing the mechanism to fix atmospheric carbon back to the Earth, but it seems that deforestation could be a double blow – it degrades the soil, allowing nutrients previously locked-up in the rainforest to run into our rivers and feed the bacteria-viral loop.

The rivers are well-oxygenated by their flow. So, with plenty of food and lots of oxygen, all the necessary factors exist for bacterial populations to boom and stimulate the bacterial–viral cycle to rapidly return terrestrial carbon to the atmosphere.

This is a gaping hole in our understanding of the natural carbon cycle. We need to close this knowledge gap firstly by confirming where this carbon comes from and how it gets back into the atmosphere, and then look at land and water management changes to restore and balance bacterial return of the greenhouse gases to the atmosphere.

In April I moved my research to the rainforest jungles of Central America with the aim of finding the missing carbon and its pathway back to the atmosphere. I am convinced it is through the bacteria–viral cycle in the water associated with the rainforests. I just have to prove it.

My aim is to describe the CO_2 pathway back to the atmosphere by working with three major research units of the Smithsonian Institute in the USA to answer the burning question: in creeks, streams, rivers and lakes, is the microbial return of CO_2 to the atmosphere the missing link in the global carbon cycle?

I am measuring microbial respiration in water with experts in plant and atmospheric research at the Smithsonian Institute, first in the rainforests of Panama and then the temperate forests around Harvard University in Cambridge, Massachusetts, to show what proportion of the production passes through aquatic microbial processes in both tropical and temperate forests.

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