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Science FINDINGS

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

FOOD FOR FISH, FOOD FOR THOUGHT: MANAGING THE INVISIBLE COMPONENTS OF STREAMS

Vegetation along fish-bearing streams supports a diversity of invertebrates that in turn feed young salmon and other fish. Scientists have measured this "insect rain" in streams over a variety of riparian conditions.

"'Tis true; there's magic in the web of it. . ."
William Shakespeare 1564-1616

What if dead salmon turn out to be as important as live salmon in restoring fisheries? What if fishless headwater streams are crucial for feeding fish? What if managers can't even see the stuff they're trying to manage for?

From within the complex web of streams that makes up many Alaska watersheds is coming a complex web of new questions about how streams feed their inhabitants. Many of the processes that provide food for streams and fish are nearly invisible to the human eye and so have received little attention, until recently.

"Most of the focus to date has been on habitat. But habitat is just part of the story—fish need food as well as shelter," says Mark Wipfli, a research ecologist with the PNW Research Station in Juneau, Alaska. "There is also an element of disbelief: what we're looking at is not big and obvious like woody debris, yet so much of what is important is not readily visible. You really need to look closely to see it all."

IN SUMMARY

Over the years, scientists have published many results from studies about the importance of habitat such as woody debris for supporting fish populations. They also have learned much about the ways in which land management activities can enhance or degrade such habitat. They know much less, however, about the food half of this food-and-shelter equation.

In the nutrient-poor streams of Alaska, the mystery of how those streams are so productive of salmon is beginning to be solved by investigating the nutritional links between organisms and among ecosystems—many of which are nearly invisible. Crucial roles seemingly are played by fishless headwater streams, riparian vegetation along fish-bearing streams, and nutrients delivered from the ocean from salmon for stream productivity in Alaska. The unseen connections of this vastly dispersed food web has significant implications for management and restoration activities that managers are beginning to recognize.

What set Wipfli on the trail of invisible trophic (nutritional) processes, like movement of nutrients, or prey and detritus within a food web? It was something out of sight: he noticed an absence of large, conspicuous insects.

"Coming from the lower 48, I was used to an abundance of insects in and around streams, and yet here were some of the most productive salmon streams in the world, with little visible food!" he recalls. Scraping rocks revealed that there are indeed tiny invertebrates there, but because of the underlying geology, streams in Alaska are comparatively poor in the nutrients that usually allow their food to grow.

So where is the food coming from?

KEY FINDINGS

- Fishless headwater streams are crucial conduits of food for fishes and other aquatic fauna that live downstream. Woody debris and sediment dynamics in these headwater habitats influence invertebrate communities.
- Riparian vegetation along fish-bearing streams is a key part of riverine food webs. Invertebrates living in forest litter, on understory plants, and within forest canopies, fall into streams, and can provide most of the prey eaten by young fish.
- Forest type plays a major role in determining the amount and quality of food entering streams. Red alder generally provides more prey than conifers.
- Anadromous fish such as salmon contribute tons of key nutrients to freshwater ecosystems every year as they migrate to spawn and die. Aquatic-riparian food webs reap the benefits of this natural fertilization process from salmon eggs and decomposing salmon.

HEADWATER STREAMS AS FOOD PIPES

It is well established that movements of prey and detritus among habitats can strongly influence populations, food webs, community dynamics, and ecosystem processes. When a food web is subsidized from outside sources, its productivity can increase, and thereby benefit vertebrate and invertebrate populations.

"Our investigations show that headwaters can be critical source areas of aquatic and terrestrial invertebrates and detritus for downstream habitats," Wipfli says. "The many small streams—and in Alaska they are countless—draining these forested uplands function as energy conduits, or 'food pipes,' that subsidize downstream food webs, linking upland ecosystems with habitats lower in the catchments."

These conduits of prey and detritus are often fishless, generally in steep terrain, with shallow soils, and naturally nutrient-poor waters. Catchments in Alaska have extensive networks of such streams, with many points of contact between these channels and the downstream salmonid-producing habitats. In a steep landscape prone to sudden and frequent spates, it takes little time for inputs from the surrounding forests to move into the main stem of streams and rivers, according to Wipfli. Most nutrient and detritus storage is likely to occur in valley bottoms.

"The function of headwater streams is not well understood, but we do know that many of them feed into salmonid-rearing habitats," says Wipfli. "Managers and policymakers are struggling with the protection issues over these streams, so ours has been largely policy-driven research."

If the food pipes carry their contributions in the form of leaves and needles and critters dropping into the water, what happens when management activities such as a clearcut, or alternatives to clearcutting, interrupt this process?

"We can only conclude that past, existing, and proposed timber harvesting, including cleacutting and alternatives to clearcutting, that lead to altered riparian forest canopies in these high-gradient forests may cause shifts in headwater stream function and productivity," Wipfli confirms. "We predict that partial or complete riparian forest canopy removal will initially reduce the amount of introduced material and increase primary production within the stream because of greater solar radiation."

Furthermore, terrestrial invertebrate inputs into these streams is likely to change owing

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to the temporary loss of riparian plants, or changes in plant species composition. It is conceivable, however, that some "intermediate" alternative harvesting strategies—somewhere between a no cut and a clearcut—may actually improve headwater productivity and transport of material downstream. This would result from the combination of increased solar radiation and continued input from trees and understory vegetation that remains, Wipfli explains, provided that the structural integrity of the streams is not compromised.

And some of that vegetation turns out to be surprisingly beneficial.

LAND MANAGEMENT IMPLICATIONS

- Young-growth forest management seems promising as a mechanism for enhancing and restoring stream function. Some alternatives to clearcutting could protect or even elevate stream productivity (provided physical processes are not compromised).
- Stream buffer protection on headwater steams will benefit from consideration of scientific data on food web productivity.
- Young-growth forests in Alaska and throughout the Pacific Northwest may be managed to enhance food resources for fish and wildlife, now that terrestrial arthropod communities and their contribution to the food web are better understood.
- Salmon fisheries management needs to encompass the seascape bearing in mind other values, such as ecosystem nutrition, plants, and wildlife.
- Watershed fertility once provided by healthy salmon runs may need to be restored before salmon populations can recover in places like California, Oregon and Washington.

"NATURE'S BAND-AID" AS FOOD PROVIDER

Forest management plans for southeast Alaska will include timber harvesting in forested headwaters, which include the many small, fishless streams, which carry little or no riparian buffer protection during logging operations.

To better understand the potential effects of forest type and condition on food web dynamics, Wipfli and colleagues sampled 24 fishless headwater streams across four riparian canopy types: old growth, clearcut, young-growth alder (35 to 40 years post-cut), and young-growth conifer.

The researchers found that young-growth alder sites exported significantly more invertebrates and detritus than did young-growth conifer sites, whereas no significant differences were observed between other canopy types.

"Alder appears to influence the link between terrestrial and aquatic systems in headwaters and between upland forests and downstream habitats," he notes. "These results suggest that maintaining an alder component in upland forests after timber harvest should increase the productivity of headwater streams, thereby benefiting downstream salmonid-bearing food webs that receive prey and detritus from these upland habitats."

What is alder's magic?

Alder fixes nitrogen that benefits returning conifers after harvest. Although alder cannot replace the benefits of large conifer trees as a source of large wood, it can serve as a transient source of wood in small streams, especially as it regenerates quickly after clearcuts. And now these results suggest it is a productive food source for riverine communities as well.

"As a deciduous species, it tends to be more desirable because it is palatable, and nutritious, and doesn't have any secondary compounds acting as insecticides that are often found in other species," Wipfli explains.

So when you add to this that young-growth alder canopies provide up to 300 percent more invertebrates and detritus for the benefit of downstream communities, alder again proves to be an excellent, if temporary, solution to a significant food web challenge.

What's more, alder occurs in many settings around the world, so these data may be transferable to many riparian management scenarios.

It is not only alder, however, that stands out as a food provider. Forest type in general, along with its associated understory and forest litter, seems to play a major role in the amount and quality—for example, crusty beetles versus succulent caterpillar larvae—of food entering streams and ultimately affecting fish populations, Wipfli explains. Deciduous trees generally house more invertebrate species than do conifers, and aerial invertebrates respond differently to different tree species. He notes that types of invertebrates also differ markedly among plant species, thereby suggesting that a broad mix of vegetation is important in providing a steady and diverse food source.

Invertebrates living in forest litter, or in understory plants, and within forest canopies provide about half of all prey eaten by young salmon, trout, and char. These terrestrial invertebrates, already so substantial a portion of juvenile salmon diets, can help subsidize aquatic invertebrate inputs after disturbance to a stream.

Thus riparian forest management practices in general, which need to look at both tree species and density of understory, may profoundly effect food resources for fish. Young-growth forest management, such as stand thinning, holds much promise for enhancing and restoring important headwater function, Wipfli says.

And then there are the ocean effects.

THE OCEAN IN THE FOREST

Spawn and die. The crazy miracle of salmon reproduction turns out to be about both those events. It's obvious what they're doing when they spawn. When they die, on the other hand, the unseen part of the sacrifice is that they are feeding their offspring with nutrients and energy gathered during their long ocean voyage.

"Anadromous fish such as salmon contribute literally tons of nutrients necessary for growth to freshwater ecosystems each year as they migrate to spawn and die in streams and lakes throughout the Pacific Rim," Wipfli explains. "Aquatic-riparian food webs reap the benefits of the natural fertilization process from decomposing salmon. Algae, bacteria, invertebrates, and fish, including young salmon, trout, and char feast on this food from the sea."

More spawners translate into higher nutrient loads and more energy-rich biomass for scavengers and detritus-eaters, in turn potentially providing more prey for fish. Wipfli points out that in ecosystems that are naturally limited in nutrients, even a small pulse of nutrients can have a major effect.

Salmon are perfect providers of nourishment for various reasons, he says. They are nutrient-rich and provide lipids and other biochemicals; their runs often span several months of the year and can achieve high numbers; they decompose slowly, metering nutrient release over time; and they are consumed by many vertebrates and invertebrates in both freshwater and riparian food webs.

Fish themselves consume salmon tissue and eggs, often receiving this food source in the latter half of summer and fall, just as other food sources may be declining. And, of course, if carcass tissue is not available because it has been washed away or buried, remember that invertebrates may facilitate the transfer of marine-derived nutrients by acting as conduit between the carcass and other invertebrates or vertebrates further up the food chain, Wipfli says.

And after salmon die, frequent flooding and scavenging activities by vertebrates spread the carcasses throughout riparian habitats. In this way, salmon and other anadromous species help sustain a positive feedback loop that both nourishes their progeny and supports other salmon-dependent species.

The problem with such a feedback mechanism is that any imbalance in any part of the cycle may cause the whole system to crash. Put another way, the watershed fertility once provided by healthy runs of salmon returning from the ocean may be essential to recovery of declining salmon stocks. But if salmon are declining, how can they provide the nutrients?

JUMP-STARTING AILING RUNS

Wipfli and colleagues are currently conducting experiments to test alternative methods of getting nutrients into streams where runs may be declining. One experiment involved placing salmon carcasses in selected natural and artificial channels.

The results showed that all stream responses (at multiple trophic levels in the food web) increased after carcass addition; trout, char, and young coho salmon grew significantly faster within the two months of adding carcasses. In addition, he notes, the fish maintained their assimilated body mass (lipid reserves and fatty acid levels in fish were also much higher in fish exposed to salmon carcasses) into the following spring, 7 months after carcass placement.

"This study illustrated that marine nutrients and energy from salmon spawners improve the body fitness of resident and anadromous salmonids in streams, which should increase their survival and reproduction, and ultimately freshwater and marine production," Wipfli says.

How many carcasses achieve this improvement? Wipfli cites tentative numbers only, but says results suggest one carcass per square meter appears to offer a substantial nutrient supply, with increments of improvement above that number being less notable.

The other experiment to supplement declining nutrients used commercial fertilizer, but Wipfli is cautious about this approach.

"Artificial nutrients should provide some level of increased production and food web nutrition, and therefore may at least help head these systems toward recovery," he says. "However, if these food webs require more than simply nutrients (e.g., carbon) to achieve a critical level of community nutrition, and it appears they do, then commercial fertilizers or other inorganic replacements clearly will not substitute all the benefits of spawners."

Beware the quick answer, he says, and remember the importance of fatty acids and other biochemicals in the nutritional health of the community.

"Clearly, we need to understand the marine-derived nutrient mechanisms better. Watersheds likely all respond to marine nutrient loading but probably do so differently. System-specific chemical, physical, and biological processes operating within a watershed likely will interact to regulate nutrient-loading effects," he says.

WRITER'S PROFILE

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FOOD FROM MULTIPLE SOURCES

"Maintaining productive salmonid fisheries in southeastern Alaska is critical to the economy and quality of life of peoples of this region; preserving riparian and stream productivity is essential for sustaining this resource," Wipfli has written.

He believes food comes into the stream from four different important sources. Wipfli and colleagues are investigating three of the food sources, which include headwater streams, which bring rapid influxes from the steep uplands that form the upper third of a watershed; foods that fall into the stream from riparian vegetation along fish-bearing streams; and food that comes literally upstream from the ocean. The fourth food source is in-stream and hyporheic (below the stream bed) production.

"It's not easy to assess the relative levels of importance of these four inputs to food webs," he says, "but we do see that each has an area of influence. As you get closer to marine habitats, for example, you see a far greater influence from marine nutrients. The whole dynamic emphasizes the importance of links, of the connections between ocean and land, main stem and headwaters."

What seems to emerge most clearly from this research is that often the nutritional links within this extensive land-sea food web have been overlooked or not understood in forest and fisheries management. It is time, Wipfli notes, to consider more than the four H's (harvest, hatcheries, hydropower, and habitat) when we formulate management plans for restoring fisheries and watershed health in general.

"Restoring and protecting stocks may have more to do with restoring nutrients, food abundance and nutrition, as restoring habitat, fish passage, and genetic diversity," he says. The challenge will be to manage for food as well as shelter, to manage, in large part, for the invisible.

Artificial streams set up in southeast Alaska have aided stream research by providing high replication under field conditions.

FOR FURTHER READING

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