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REPORT 6704
(Scarification & Water Velocity)

Date: September 17, 2019

To: Richard Marovich, Putah Creek Streamkeeper

Scarification & Water Velocity Data - Survey In-Progress

Background

Water velocity represents one of the most important environmental factors affecting stream biota. (NIVA 2002) Very slow flows create the most unfavorable conditions for life in a stream. Such conditions typically will not support efficient salmon and trout spawning or a healthy macroinvertebrate population.

Granted, stream velocity is a complex subject affected by water volume, slope, stream width, stream depth, and the roughness or smoothness of the benthos. That said, I believe that adjusting the water velocity in Lower Putah Creek is the most significant restoration effort that can be accomplished. The effort can easily be done during the scarification process.

After observing hundreds of West Coast, Rocky Mountain and Alaskan waterways (casual and formal surveys looking for benthic macroinvertebrates and salmonid species) that feature natural, in-progress and restored conditions it is obvious that the on-going scarification project in Lower Putah Creek has features that would be prudent to be developed and shared with other waterway managers. Scarification opens interstitial spaces; when creek width and depth is considered, it also increases the water velocity which has numerous benefits beyond simply improving interstitial spaces. Scarification without correcting sub-optimum water velocity is only partially successful and will probably not benefit spawning fish, benthic macroinvertebrate (BMI) communities and indirectly other riparian wildlife species. That can be observed directly at several sites in Lower Putah Creek where the creek width approaches 30 feet and the water velocity is minimal (see comparative images on page 4). Certain other sites that are post-scarification have essentially retained the positive results from the scarification process.

Baetis (mayfly) adult that is important in many waterways as food for juvenile salmonids.

Objective: By the end of October 2019, I want to have completed a "specific point" water velocity study to determine the ideal width, depth and water velocity that can be followed during future scarification projects.

Arctic Char, a brightly-colored salmonid, filmed in Yaku Creek, a small Alaskan waterway that eventually flows into Bristol Bay. The Char were filmed / photographed during a trip to observe management, restoration and protection of salmon spawning areas within the Bristol Bay watershed. Ken Davis Image.

Water Velocity Monitoring Plan:

Measuring average water velocity is an important factor when monitoring benthic macroinvertebrates, former scarification sites, and potential sites for scarification. During the next month, I plan to measure the average water velocity at scarification sites that withstood the 2019 floods and other sites that were negatively impacted by the flood. It has been noted that some sites that remain with "Scarification Benefits" appear to have water velocity that mobilizes sediment, keeps the interstitial spaces open, encourages health BMI communities, and will provide ideal spawning sites for native rainbow trout and Chinook salmon. Considering the relatively constant water volume supplied to Lower Putah Creek via the Putah Creek Accord, and to maintain what will be referred to as an "Ideal Water Velocity" the creek has to be "XX" feet wide and "XX" feet deep. Obviously, if the width or the depth are changed, the water velocity will decrease or increase. Neither condition will be beneficial for the restoration of BMI resources or spawning habitat. Avoiding physical factor templates that dictate creek width and depth, some restoration efforts consider benthic conditions and aquatic invertebrate species during the restoration process. Fish food is necessary for healthy salmonid populations. Consider the following quote from *Science Findings*, a research paper from the U.S. Forest Service (Article attached to this document:

> *"Ask J. Ryan Bellmore if a river has suitable habitat for salmon and steelhead, and he won't look for physical indicators such as gravel beds or course woody debris. Instead, he looks for the fishes' prey - caddisfly and mayfly larvae, snails, and other invertebrates. For Bellmore, a research biologist with the U.S. Forest Service Pacific Northwest Research Station, it's both a river's food webs and its physical habitat features that determine its capacity for sustaining healthy salmon and steelhead populations. "If you have no food, then you have no fish," he says. If we want to understand the capacity of river ecosystems to sustain fish and how that might change in the future, we need to understand the flows of energy and nutrients that support these species."*

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Putah Creek Experience: According to the work and observations of SCWA employee Rick Fowler, while conducing scarification operations, the ideal creek width for normal Putah Creek flows is 10-12 feet. My creekside observations, spawning and redd measurements, BMI studies, subsurface video projects, and cobble measurements support the concept that 10-12 foot width (or less) might be the ideal width to produce a functional water velocity in Lower Putah Creek. During the next month, I will endeavor to determine the ideal "width-depth-velocity" formula for the Scarification Project.

CONCLUSIONS

1. My work on other waterways to determine relative health via BMI communities, trout populations, and observations at more than 500 waterways on the West Coast, in the Rocky Mountains, Northern East Coast states, and Alaska shows that when other features such as water discharge and water temperature are appropriate for the site, that velocity is essential for healthy BMI communities and spawning conditions.

2. BMI communities generally respond to open cobble (freestone) conditions if the stream velocity is appropriate.

3. Sediment mobilization is typically accomplished when the velocity is appropriate for the site.

4. NZMS density can be diminished with the appropriate velocity.

5. Open interstitial spaces, necessary for robust BMI communities and spawning salmon and trout, is accomplished by the appropriate velocity.

6. Other riparian wildlife, such as birds, benefit due to the increased density of BMI communities when the velocity is appropriate.

7. The ultimate increase in spawning salmon populations will benefit large predators such as Bald Eagles which were documented in 2018 feeding on salmon carcasses.

Amiocentrus aspilus larvae, a common and important caddisfly species found in sections of Putah Creek (IDR). The larvae use specific plant materials to form the case. Caddisfly species such as Amiocentrus require fast-flowing water.

Morales Scarification site. Image taken 8/21/2019 shows improved flow that can be easily adjusted during the scarification process and dramatically improved benthic condition that supports healthy macroinvertebrate populations. Spawning salmon are also aided by the open-cobble environment as they can establish healthy redds significantly quicker than areas that do not offer open cobble.

WPCP Phase 3 site. Image taken 8/26/2019 shows slow velocity, possibly due to overly wide creekbed, and poor benthic conditions that will not support a healthy macroinvertebrate population. The less than appropriate water velocity will not mobilize sediment.

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West Fork of the Little Colorado River, near Greer Arizona. Home to the threatened Apache trout, the Little Colorado River has sections that are being restored (see image below)

West Fork of the Little Colorado River, is being restored using some techniques used in Lower Putah Creek. The main difference is that they have created the ideal water velocity by limiting the width of the creek bed. The velocity and structure create optimum conditions for the Apache Trout and prey base - macroinvertebrates.

Wolf Creek, home to the threatened Walker Lahontan Cutthroat Trout. The creek has features, that include appropriate boulders, ample cobble, and well placed (naturally) willows and other riparian vegetation that provide cover for the rare trout.

Whitewater Creek New Mexico is undergoing massive restoration and “enhancement” to preserve and protect the Gila Trout, one of the rarest trout species in the United States. The Gila Trout is federally threatened.

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INSIDE

Science FINDINGS

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

River Food Webs: Incorporating Nature's Invisible Fabric into River Management

David Walsh

An aerial view of a restoration project on the Methow River, Washington, designed to improve fish habitat and restore salmon and steelhead populations. New research is revealing the importance of considering food webs, in addition to physical habitat, in restoration efforts.

"Who looks upon a river in a meditative hour, and is not reminded of the flux of all things?"
–Ralph Waldo Emerson

Ask J. Ryan Bellmore if a river has suitable habitat for salmon and steelhead, and he won't look for physical indicators such as gravel beds or coarse woody debris. Instead, he looks for the fishes' prey—caddisfly and mayfly larvae, snails, and other invertebrates. For Bellmore, a research biologist with the U.S. Forest Service Pacific Northwest Research Station, it's both a river's food webs and its physical habitat features that determine its capability for sustaining healthy salmon and steelhead populations.

"If you have no food, then you have no fish," he says. "If we want to understand the capacity of river ecosystems to sustain fish and how that might change in the future, we need to understand the flows of energy and nutrients that support these species."

In 2007, Washington state adopted the Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan to restore sustainable populations in the upper Columbia River. The Methow River populations were considered to be at risk of extinction. Located in north-central Washington, the Methow is one of six major subbasins in the upper Columbia River basin. It's estimated that more than 60,000 salmon—coho, spring and summer Chinook, and steelhead—would swim roughly 500 miles from the Pacific Ocean to

IN SUMMARY

Increasing the population of spring Chinook salmon and summer steelhead in Washington state's Methow River is a goal of the Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan. Spring Chinook salmon and summer steelhead are listed as endangered and threatened, respectively, under the Endangered Species Act.

Installing logjams and reconnecting the river to its floodplain are management actions being undertaken to restore salmon habitat. However, researchers with the U.S. Forest Service Pacific Northwest Research Station, the U.S. Geological Survey, and Idaho State University found that focusing solely on physical habitat restoration overlooks the importance of maintaining the food webs supporting all river life.

When comparing prey production and habitat structure in the Methow River system, the research team found that complex floodplain landscapes support an array of food webs. Restoration actions may unintentionally alter these food webs, either to the benefit or detriment of juvenile salmon. Restoration efforts designed to protect the processes that create and maintain habitat complexity and sustain diverse food webs may be more beneficial to fish. As part of this holistic approach, the research team developed a model that allows land managers to explore how proposed river restoration projects influence river food webs and fish populations.

spawn in the Methow River prior to European settlement. Now, the numbers of salmon and steelhead returning to spawn are but a fraction of those estimated historical highs. Spring Chinook salmon and summer steelhead are listed as endangered and threatened, respectively, under the Endangered Species Act. Coho salmon were considered extirpated in the upper Columbia River. Until their reintroduction in the late 1990s, coho salmon hadn't spawned in the Methow River for more than 100 years.

Habitat restoration is one management tool for restoring these populations. Common techniques include installing logjams to create pools of deep, cool water; replanting riparian vegetation to shade the stream; and removing levees to reconnect river channels with floodplains. Through these physical alternations, it's assumed the restored habitat will produce and support more salmon. However, Bellmore and his colleagues, Joseph Benjamin, with the U.S. Geological Survey (USGS), and Colden Baxter, with Idaho State University's Stream Ecology Center, caution that focusing primarily on habitat restoration overlooks the role of food webs that actually sustain fish populations.

"There's more going on within these streams than just the fish we like to catch," says Benjamin, an ecologist at the USGS Forest and Rangeland Ecosystem Science Center. "There's also a whole community of fish competing with and preying upon those fish. There are also smaller organisms providing energy and nutrients—those insects you mimic when you're fly fishing."

KEY FINDINGS

- Complex or "messy" landscapes such as floodplains support a mosaic of different aquatic food webs used by juvenile salmon. Collectively, these food webs are important for salmon recovery and persistence.
- Although river restoration projects are intended to benefit juvenile salmon, restoration also affects the broader web of life that includes their competitors, predators, and prey. Changes in the food web could positively or negatively affect salmon, and may or may not address the factors that actually limit salmon populations.
- Changes to the structure of a food web, such as those that accompany the spread of invasive species, may negate desired responses to river restoration by rerouting the flows of energy and nutrients supporting salmon.

This begs the question: If food webs are crucial to salmon survival, why aren't they being more explicitly considered when designing restoration projects?

"You can't easily visualize food webs," Bellmore admits. "It's easy to see and measure physical habitat structure, such as pools and logjams, and it's relatively easy to see and count the number of fish in a stream. Yet actually seeing how fishes interact with one another and the larger food web, it's not a very tangible thing in people's minds."

Studying Food Webs Means Getting Your Hands Dirty

In 2008, the U.S. Geological Survey, with funding from the U.S. Bureau of Reclamation, asked Baxter to evaluate the potential of implementing habitat restoration projects on the Methow River to fulfill the goals of the Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan.

"Although the river is in very good condition in terms of habitat and has a natural flow regime, managers wanted to explore opportunities to restore connectivity to river-floodplain habitat or manipulate habitat to improve conditions for salmon and steelhead rearing," he says.

As a professor who specializes in freshwater ecology and food webs, Baxter sought to understand how the river's food webs were sustaining its existing fish populations.

Bellmore, then a graduate student at the Stream Ecology Center where Baxter conducts research, was recruited to investigate the food webs. He and a sampling crew visited the Methow River four times between summer 2009 and spring 2010, taking measurements and collecting samples at sites along the main channel and five side channels—two of which remained connected to the main channel year-round, and three that were disconnected from the main channel in the summer.

The sampling crew recorded water temperature and depth, counted fish—collecting the stomach contents of some—and collected living invertebrates from the streambed. In the lab, Bellmore and others painstakingly identified each invertebrate, such as mayflies or beetles, found in fish stomachs and the streambed.

"This data collection provides the linkages, the food web connections," Bellmore explains. "It allows us to draw arrows from one organism to another." However, he also wanted to analyze the strength of the linkages: What invertebrate prey items were most important for sustaining fish populations in each habitat? How was the invertebrate population sustaining the fishes, and was there evidence that food availability was limiting these populations?

Ryan Bellmore

To better understand the Methow River's food webs, Ryan Bellmore and the sampling crew recorded water temperatures and depth, counted fish, and collected invertebrates pictured on page 3.

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Forest Service

By collecting fish and invertebrate data throughout the year and in different habitats, Bellmore could calculate their respective population's accumulation of biomass on an annual basis. In other words, the analysis would show how the fish were growing in relation to the production of invertebrates available in each habitat. Combining the two measurements generated a picture of how much of each invertebrate prey was being consumed (or not consumed) by each fish species.

"We found that in all of the floodplain habitats, there appeared to be more food than fish demand for that food," Bellmore says. This finding suggests that these habitats can support more fish than are currently using the river and its floodplain habitats.

One likely explanation for this disconnect is that insufficient numbers of adult salmon and steelhead are returning to the Methow owing to downstream factors, such as the negative impacts associated with dams and reservoirs on the mainstem of the Columbia River.

These food web studies also point to a broader ecological finding: riverine food webs are incredibly complex, and this complexity itself may contribute to ecosystem stability and resilience. Using their food web data, Bellmore and Baxter conducted a series of analyses to evaluate how the Methow River's spatial complexity influenced the strength of food web interactions. By quantifying these interactions across the floodplain, the researchers found that spatial complexity reduced the impact of fish predators on invertebrate prey.

"Ecological theory suggests that the strength of interactions between predators and prey is associated with ecosystem stability and maintaining the diversity of species," Bellmore says. "When you have a lot of strong interactions between predators and prey, and predators are strongly controlling prey populations, you tend to have ecosystems that are less stable. They're more prone to destabilizing forces that can drive species to extinction."

Although rivers are inherently dynamic, this finding suggests that spatial complexity may promote the maintenance of species diversity

Colden Baxter

To calculate the number and type of prey that fish were consuming, researchers analyzed stomach contents of fish.

by reducing the strength of interactions between fishes and their prey. The results also suggest that striving for idealized types of habitats, such as streams with logjams or year-round side channels, may be inappropriate. Restoration activities that take a cookie-cutter approach to creating the same habitat conditions everywhere may be misguided because they don't necessarily create a diversity of habitats and their associated food webs.

Baxter says these findings suggest, "We not only need to account for food web relationships and interactions when managing salmon and steelhead, but we should also consider managing river systems to conserve and preserve the processes that create and maintain spatial complexity."

When their study results were published, natural resource managers and scientists took notice. Robert Naiman, a professor emeritus with the University of Washington and former chairman of the Northwest Power and Conservation Council's Independent Scientific Advisory Board, says that, at first, he did not fully appreciate the scope and significance of Bellmore's research. However, once he recognized that Bellmore and Baxter were calling attention to processes underpinning salmon recovery and the need for a holistic approach to restoration, Naiman became a proponent of the research. He and other program reviewers had been advocating a similar approach for several years.

"Restoration actions make the assumption it's for the benefit of salmon, but it may not be," Naiman explains. "In reality, restoration actions may create great habitat for the predators of young salmon—and other fish species—and that is quantified during food web studies. One must consider the standing biomass and trophic interactions of all creatures living in and around the stream."

Modeling a Dynamic Food Web

After graduating from Idaho State University in 2011, Bellmore joined the USGS Western Fisheries Research Center, and his food web research took on a practical importance. "Bureau of Reclamation funders said this empirical food web work is really great, but what we would like are models that can help us to determine when, where, and how we should do restoration," recalls Bellmore. "What mechanisms are affecting fishes? Can we use that information to help us prioritize restoration better and determine what ultimately is limiting fish production?"

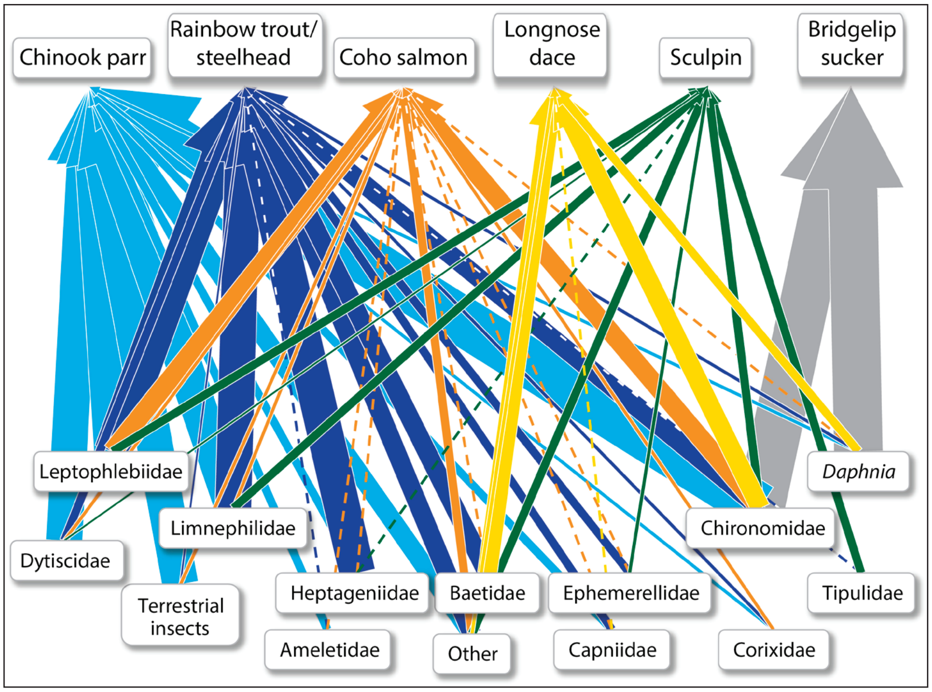
Bellmore's first foray into modeling was quantifying the seasonal dynamics of periphyton—the microbe mixture of algae, cyanobacteria, and other organisms found on streambeds that is the foundation of river food webs. Working with the Bureau of Reclamation's Michael Newsom and Washington State University's Alex Fremier and Francine Mejia, Bellmore and the team used the model to evaluate the effects of spawning salmon on periphyton communities. "It is frequently assumed that marine-derived nutrients delivered by salmon stimulate the productivity of the food web from the bottom up by contributing labile nutrients that increase periphyton production," says Bellmore. However, simulations from their model suggested that the effects of salmon on periphyton dynamics are likely to be relatively short term and have little effect on food availability for fish.

Colden Baxter

Stonefly

Colden Baxter

Caddisfly



Kathryn Ronnenberg

A visual representation of one food web in the Methow River. The thicker the arrow between prey and fish, the more fish consume of that invertebrate. (adapted from Bellmore et al. 2013).

Building this model proved quite easy compared to Bellmore's next assignment: designing a model that simulated the effects of restoration projects on the entire food web. Such a model would not only have to include a stream's periphyton production, it would also need to include the contribution of leaf litter and terrestrial invertebrates that fall into the stream as well as the food web pathways by which these resources find their way to fish. Numerous environmental conditions of the stream and riparian zone, such as water temperature, flow regime, channel morphology, and the composition of riparian vegetation, would have to be included because these variables also affect food web productivity. The complexity and number of these variables are one reason few riverine modeling efforts have been conducted.

Bellmore and Benjamin took on the challenge. Building a food web model of fish-bearing streams involved "a heck of a lot of reading" to develop the framework for a simulated river system, says Benjamin. An important step in all modeling is identifying which real-world components to include and which parts can be simplified. For example, all the fish were lumped into one or two groups instead of several different species. The final model represented a generalized version of river food webs that incorporated all the primary energy and nutrient pathways that sustain fish populations. This generalized web was then mathematically linked to the environmental conditions of the stream and its riparian zone.

To test their model, Bellmore and Benjamin ran simulations in the same Methow River floodplain reach where they conducted earlier empirical food web research. By comparing the model simulations to empirical data, the researchers found the model generated realistic fish, invertebrate, and periphyton abundances.

They also explored how changes in the river—such as the introduction of invasive species—might affect the success of restoration projects. Bellmore and Benjamin modified the model food web by adding populations of nonnative fish and snails. The nonnative fish represented a larger predatory fish species such as the nonnative smallmouth bass, and the snail represented invasive New Zealand mudsnails. Three commonly employed river restoration strategies were then run through the model: riparian vegetation restoration, adding salmon carcasses to increase nutrient availability, and side-channel reconnection. The simulations suggest that the occurrence of nonnative snails and fish modified the modeled food web, which strongly influenced the native fish's response to restoration actions by decreasing the availability for their prey, and consequentially their growth. For Bellmore and Benjamin, this demonstrated that forecasting responses to restoration needs to account for the structure of food webs.

This modeling exercise also illustrates how food web models can be useful tools to explore responses of river restoration actions, from direct manipulations of the food web (e.g., salmon carcass addition or invasive species), to those focused on modifying the river's physical structure. "Dynamic food web models, such as the model we developed, can improve decisionmaking by fostering a deeper understanding of ecosystem complexity and interconnectedness," says Bellmore. The team also emphasizes that this model is a tool best used within the context of an adaptive management plan.

Modeling and On-the-Ground Restoration

The Aquatic Trophic Productivity Model was released in 2016 and has been positively received. In addition to continued research in the Methow River, Bellmore and Benjamin are working with Andy Kohler and David Richardson, biologists with the Shoshone-Bannock Tribes of Fort Hall, to evaluate the efficacy of adding salmon carcasses to rivers to increase salmon populations. Bellmore is also working with colleagues at the Alaska Coastal Rainforest Center and the University of Alaska Southeast to evaluate how river food webs and salmon might respond to ongoing climate change and forest management practices in southeast Alaska.

"It's gratifying to see the model being used and that folks are expressing an interest in using it," Benjamin says. "It's not just a tool that we created and it's being shelved." Building the model also revealed gaps in the current empirical knowledge of river ecology, he adds. "Those gaps are helping us identify where we need to do additional research, such as understanding the physiology of the aquatic insects that fishes eat."

Naiman sees the model's results demonstrating the value of a holistic approach to restoration. "We need more work like what Bellmore, Baxter, and others are doing because it's about the mechanics of how ecological systems work. It tells us whether or not the restoration actions we're spending millions of dollars on in the Columbia Basin are actually working to the benefit of the salmon."

And he sees another food web question looming on the horizon that needs answering—how contaminants are affecting salmon restoration. "Food webs are also the way by which contaminants are transferred, and we know very little about that in the Columbia Basin," Naiman says. "This may be one way the young salmon populations are being throttled, specifically by the toxic mix of chemicals that are everywhere now."

"Let's face it, the universe is messy. It is nonlinear, turbulent, and chaotic. It is dynamic....It self-organizes and evolves. It creates diversity, not uniformity. That's what makes the world interesting, that's what makes it beautiful, and that's what makes it work."

—Donella Meadows, environmental scientist

LAND MANAGEMENT IMPLICATIONS

- Assessing responses to river management has traditionally focused on physical habitat structure. However, understanding food web dynamics is also necessary for assessing factors that limit fish populations and evaluating restoration success.
- Messy landscapes promote complex and resilient food webs. Managing for resilient food webs may be as simple as maintaining, conserving, and—when necessary—restoring the processes that create and maintain habitat heterogeneity.
- Considering the context of local food webs is important. In some areas, river restoration actions, such as physical habitat manipulation or salmon carcass additions could have a less-than-desired, or even negative, effect.
- Invasive species may significantly alter river food webs. Different restoration approaches may be needed for these altered ecosystems.

J. Ryan Bellmore

Habitat restoration is a management tool for restoring salmon and steelhead populations. Installing logjams or reconnecting river channels to their floodplain, as shown here, could change food webs in ways that may or may not benefit salmon and steelhead.

Writer's Profile

Andrea Watts is a freelance science writer who specializes in covering topics related to natural resources. Her portfolio is available at http://www.wattswritings.wordpress.com.

For Further Reading

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