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Removing San Clemente Dam Did More Than Restore Fish Passage

by Thomas H. Williams, Amy E. East, Douglas P. Smith, David A. Broughton, Nate Mantua and Lee R. Harrison

— *NOAA,USGS, California State University*—

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In November 2015 on the Carmel River on California's central coast, engineers removed the San Clemente Dam to address seismic risk and structural concerns. At 32 meters high, the San Clemente Dam was one of the tallest dams yet removed in the U.S. and was, to date, the largest removal in California. Along with the dam's seismic hazards, the dam's demolition eliminated a barrier to fish migration and an inefficient fish ladder, which had long limited both the upstream and downstream movement by anadromous steelhead trout (*Oncorhynchus mykiss*) and the downstream movement of wood and sediment. In many ways, the scale of construction for this removal was unprecedented in the Western U.S. because, unlike previous dam removals in the Pacific Northwest, the removal of San Clemente Dam included the construction of a re-route channel that bypassed two-thirds of the reservoir sediment. The re-route was designed to minimize the chance that reservoir sediment, which had accumulated since the dam was constructed in 1921, would move downstream and create a flood risk for structures on the floodplain of the lower Carmel River Valley. Engineers re-routed the Carmel River through a bedrock ridge that separated it from a tributary, San Clemente Creek, creating a new confluence with that tributary 700 meters upstream from the former location (Figure 1). Through this engineering effort, only sediment in the furthest upstream third of the reservoir became available for natural transport by the river.

> *In many ways, the the removal of San Clemente Dam was unprecedented in the Western U.S.*

The removal of San Clemente Dam is the largest dam removal in a Mediterranean hydroclimatic setting to date. The Carmel watershed's Mediterranean climate is characterized by dry, foggy summers and infrequent, large winter rainstorms, unlike the climate found in the Pacific Northwest where recent dam removals have occurred. As more dams are removed, we see similar response patterns from each dam removal and we

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FROM THE PERCH — EDITOR'S MESSAGE

Atlantic Salmon Go Home!

by Jim Yuskavitch

My one and only experience with Atlantic salmon was in September of 1992 with long-time friend Tom Pero, now Publisher at Wild River Press, and it was a magnificent experience. Tom and I flew to Quebec's Ungava Peninsula and spent a week fishing the Meleze River, where I landed my first (and only) Atlantic salmon on a fly. I can assure you that its moniker *Salmo salar* "The Leaper" is well justified. It was a beautiful, bright fish and after admiring it for a moment, I let it slip back into that icy sub-arctic river. I believe that was the last wild Atlantic salmon I have seen.

Here on the West Coast, far from the Atlantic salmon's native ocean, it is a very different story where farmed Atlantics are confined in net pens in Puget Sound off the Washington state coast, and along the coast of British Columbia as well.

Last summer, Atlantic salmon farming made headlines throughout the Pacific Northwest when as many as 160,000 of the fish escaped from a broken pen at Cypress Island in Puget Sound, which is owned by the Canadian aquaculture company Cooke Aquaculture Pacific.

The escape set off alarms all along the coast as state officials worked to contain the escape while commercial and recreational fishers tried to capture as many of the at-large non-native salmon as possible. The escaped fish were found to have traveled as far south as the mouth of the Columbia River and north to Vancouver Island.

The initial concern was that the escaped fish would occupy native Pacific salmon and steelhead streams, but the real long-term threats from Atlantic salmon farming on the West Coast involve the spread of diseases and infecting wild salmon with sea lice that are known to be fatal to juvenile fish. And some recent research suggests that those problems may be even greater than previously thought.

For example, researchers at Simon Fraser University have found that juvenile wild Fraser River sockeye salmon that pick up heavy infestations of sea lice while passing though salmon farms eat less while they are in the ocean than uninfected fish, decreasing their growth and survival odds. In addition, a study by Chilean scientists has found that the vaccines given to farmed fish are not adequately protecting them from disease thereby making wild fish more vulnerable to outbreaks.

But on a positive note, last summer's escape also prompted Washington state legislators to propose laws ending salmon farming in Puget Sound. Before the year is out we should know if those efforts have succeeded.

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GUEST'S CORNER

Alaska Should Decide its Own Fate

Proposed Pebble Mine Still a Potential Threat

by Guido Rahr

— Wild Salmon Center —

Guido Rahr is President and CEO of the Portland, Oregon-based Wild Salmon Center. To learn more about their conservation work for wild salmon visit their website at www.wildsalmoncenter.org.

On December 21, 2017 Pebble Limited Partnership announced it had begun the process of acquiring federal permits for the Pebble Mine, in the headwaters streams that feed into Bristol Bay, Alaska. It's a day many of us have dreaded for more than a decade. Pebble also entered into a deal recently with First Quantum Minerals, a Toronto, Canada-based company with mining operations in six countries, to help fund the expensive federal permitting process.

Pebble Limited Partnership CEO Tom Collier has for months been pedaling a new and improved mine concept — one that is supposedly smaller, cleaner and takes into account Bristol Bay community concerns about wild fish, corporate trust, and transparency.

But all of these promises don't stand up to the facts, or even some of Collier's own blunt admissions.

Analysts say that the remote Pebble mineral deposit can't be developed without massive new infrastructure developments. And given the low-grade nature of the deposits, a smaller mine's returns will simply not support those sizeable infrastructure investments.

What's worse, even if the small mine concept does somehow become a reality, it is still a huge risk to wild fish. The Environmental Protection Agency found that even a mine with a small footprint of four square miles would erase dozens of miles of streams and hundreds of acres of wetlands. A proponent admitted to CNN this fall that there would almost certainly be toxic leakages from the mine. He promised that they would simply dilute across the large watersheds around Bristol Bay, with minimal impacts to fish.

Collier and Pebble continue to be confusing about their true long term plans in Bristol Bay. Despite the smaller mine described in the permit application, he told Bloomberg recently, "It wouldn't surprise any of us that are working on this particular permit application that there might be another one at some point in the future." In other words, once Pebble installs the infrastructure to transform the Bristol Bay headwaters into a mining region, the mine will grow, possibly to its feared original size.

> ***A salmon coalition is moving to protect salmon habitat across Alaska from the worst impacts of developmemt.***

Alaskans have seen through these cheap publicity stunts. Bristol Bay leaders and most community members remain adamantly opposed to the mine. Beyond the 14,000 jobs and $1.5 billion in economic benefits from Bristol Bay sockeye runs that reach up to 60 million each year, Alaska Native communities have a deeper stake in the continued health of the fishery and region. "This is a human rights issue at its core," Allanah Hurley, the executive director of United Tribes of Bristol Bay, told National Public Radio recently. "We can talk about the economics of the commercial fishery and the sport fishery all day. But when it comes down to it, this is an indigenous rights issue that all people should be concerned about."

Gov. Bill Walker said this fall, "I am not supportive of the Pebble Mine."

For Alaskans, protecting Bristol Bay is a no-brainer. Overwhelming comments from the 49th state is one reason that EPA Administrator Scott Pruitt made the unexpected decision not to scrap Clean Water Act protections for Bristol Bay in late January. Instead, he opted to let the Pebble permit run its course before making a final decision on those protections. We are spending our energy now working alongside Alaskans in the state policy arena. Beyond Pebble, Alaskans of every stripe identify salmon protections as a core priority in opinion polls. Coalitions of anglers, commercial fishermen, Alaska Native communities, and conservation-minded locals have effectively stopped damaging industrial development proposals in important salmon and trout streams in recent years. And that same salmon bloc helped put the independent Walker in the governor's mansion in 2014.

Now, a salmon coalition is advancing reform measures to protect salmon habitat across the state from the worst impacts of industrial development. These updated rules would give Alaska's great rivers and streams some buffer from the heavy impacts to habitat that we've seen in the Lower 48 — a potential stop to the vicious historical cycle of salmon habitat loss and population crashes.

As Walker heads for re-election, and the salmon habitat reforms advance, we encourage you to support grassroots efforts to get out the salmon vote and protect all of Alaska's world-class

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San Clemente Dam
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also learn new lessons that will influence future dam removals and inform the development of reasonable expectations for the response of impacted fish populations near each project.

Overview of the Watershed

The Carmel is a small (650 km^2), steep watershed dominated by chaparral vegetation and oak savannah, typical of the central California coast. Although a fairly dry region (500 mm mean annual rainfall), the upper basin is wetter and many tributaries there are naturally perennial. Along most of its length, the Carmel River alternates between bedrock and alluvial morphology, forming a gravel bed, single-thread river. Sediment supply to the river is mostly from landslides and dry ravel, which is the process of sediment bouncing or rolling down hillslopes in steep and arid or semiarid landscapes. Most housing and business development is concentrated in alluvial Carmel Valley, downstream of the dam site. The remainder of the watershed is grazing land, and the Ventana Wilderness (Los Padres National Forest), which constitutes the upper 31% of the watershed. Fires episodically impact the upper watershed and sediment dynamics in the river, although fires in 2015 and 2016 apparently had little influence on sediment dynamics near the re-route channel and dam site.

Three dams intended for water storage once existed on the Carmel River. Old Carmel River Dam was built in 1880, 1 km downstream from the later site of the San Clemente Dam; it was notched prior to 2013 to allow fish passage, and completely removed in 2016. The remaining dam on the mainstem Carmel River is the Los Padres Dam, built in 1948, which sits 11 km upstream from the newly created re-route channel and the former San Clemente Dam site. Los Padres Dam does not provide volitional upstream fish passage, but a trap and haul operation provides upstream passage to adult *O. mykiss* in the winter. A newly constructed volitional passage structure provides passage for downstream migrant *O. mykiss* during the wet season. Research efforts are underway to evaluate movement patterns and survival of downstream migrating *O. mykiss* through the reservoir upstream of Los Padres Dam and also to evaluate downstream passage at the dam. In addition, research efforts to assess the overall status of *O. mykiss* in the watershed are currently underway.

Removal of San Clemente Dam, summer 2015. Photo used with permission, California American Water.

The fundamental driver of habitat-forming processes in rivers of this region is the interplay between infrequent large winter rainstorms that trigger landslides coupled with high runoff and peak flows when most sediment movement occurs, and the longer duration periods of moderate rainfall and relative stability that promote vegetation growth along the river. As such, short-term observations of habitat-formation along the Carmel River are driven by recent rain conditions, which vary widely by season and tend to vary widely year-to-year. The river's flows often vary by three orders of magnitude seasonally and the river's entire capacity to move sediment typically occurs during a few days in the winter rainy season. The two water years after dam removal (2015-2016) saw extremely low and lower-than-average flows, respectively. In contrast, the third year (2017) saw a highly energetic series of floods, including four 2-year floods, two 10-year floods, and one 30-year flood—all within six weeks and each lasting no more than two to three days. This combination of drought and flooding conditions over this period provided a unique opportunity to observe the region's habitat-forming processes after a major dam removal in very dissimilar water years.

Overview of Steelhead and the Aquatic Community in the Carmel Watershed

Steelhead in the Carmel River were listed as threatened under the Endangered Species Act (ESA) in 1997 and are part of the South-Central California Coast Distinct Population Segment that includes coastal streams from the Pajaro River south to (but not

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including) the Santa Maria River. Throughout the 1960s and early 1970s estimates of over 1,300 adult steelhead were common and the Carmel River supported a popular sport fishery. Counts of adult steelhead over the last 22 years (1993 to 2014) from the fish ladder at San Clemente Dam have averaged approximately 380 adults per year, although the counts varied widely and did not include steelhead spawning downstream from the ladder (Figure 2). An irregular decline in numbers has occurred since the peak run in 1998. Though recent declines in 2013 and 2014 were likely influenced by drought conditions, a decline was evident prior to the recent drought. Over the past 20 years, there have been no active hatchery operations on the Carmel River, although fisheries endeavors have included management activities such as habitat restoration (gravel augmentation, estuary and riparian vegetation restoration, etc.) and a captive-rearing program for juvenile fish rescued from isolated river reaches during the dry season.

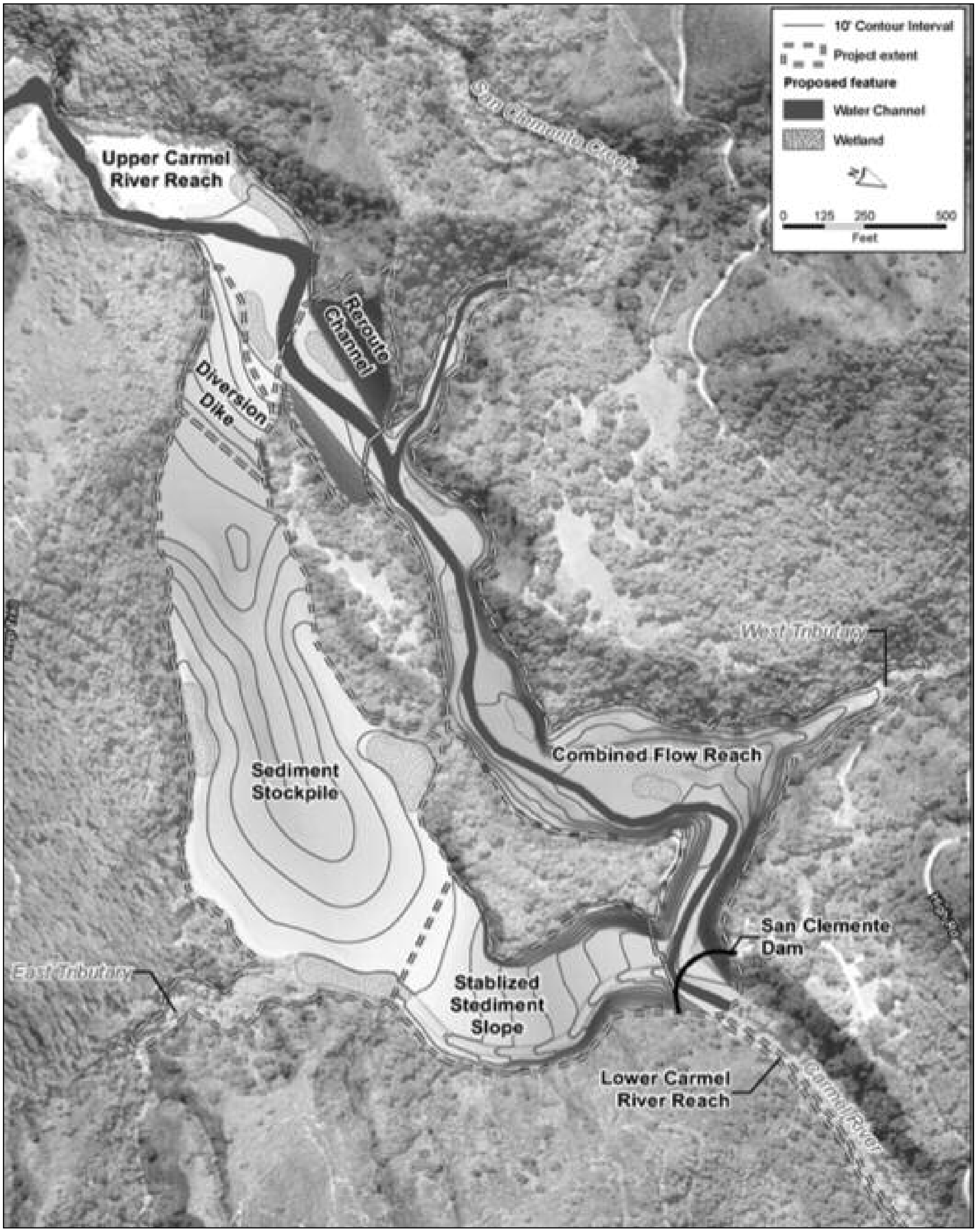

Figure 1. Map of Carmel River, San Clemente Dam, San Clemente Creek, upstream reservoir reach and re-route channel, Carmel River, California. Figure used with permission, California American Water.

In addition to the ESA-listed steelhead, ESA-listed Threatened California red-legged frog (*Rana draytonii*) occur in the watershed, and anadromous Pacific lamprey (*Entosphenus tridentatus*) are also found in the Carmel River although few, if any, have been observed upstream of San Clemente Dam prior to 2015.

Besides the impacts of the dams, *O. mykiss* in the Carmel River experience a range of threats common to Pacific salmonids throughout their range: excessive surface and groundwater

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diversions, passage impediments, channel modifications for flood control – specifically disconnection of streams from floodplains, development along stream banks and on floodplains (e.g., agricultural, residential, and commercial, flood protection), lagoon and estuary management (i.e., artificial breaching of the sandbar), and the presence of non-native organisms such as striped bass (*Marone saxatilis*) and recently observed New Zealand mud snails.

Studies to Examine Impacts of Dam Removal on Carmel River

Between 2013 and 2017, we conducted a before-after/control-impact (BACI) study to examine impacts of the dam removal on steelhead and their stream habitat. These efforts focused on physical processes and on *O. mykiss* response in 10 reaches selected for monitoring. These study reaches included nine impact reaches: one in the upstream portion of the former reservoir (above the re-route channel), one immediately downstream of San Clemente Dam, and seven additional reaches in the approximately 30 km between the dam site and the river mouth. The final reach served as our "control" and was several hundred meters upstream from the former reservoir (although downstream of Los Padres Dam).

Besides the dams, Carmel River steelhead experience a range of threats common to Pacific salmonids.

To evaluate physical processes we measured river channel topography and bed sediment grain size once per year in each reach to track the evolution of channel shape (morphology) and bed habitat composition. During the relatively dry winter immediately following dam removal (2016), we documented new sediment deposition in the first approximately 3 km downstream of the re-route channel, with new sand and gravel accumulating in deep pools. Effects of the dam removal

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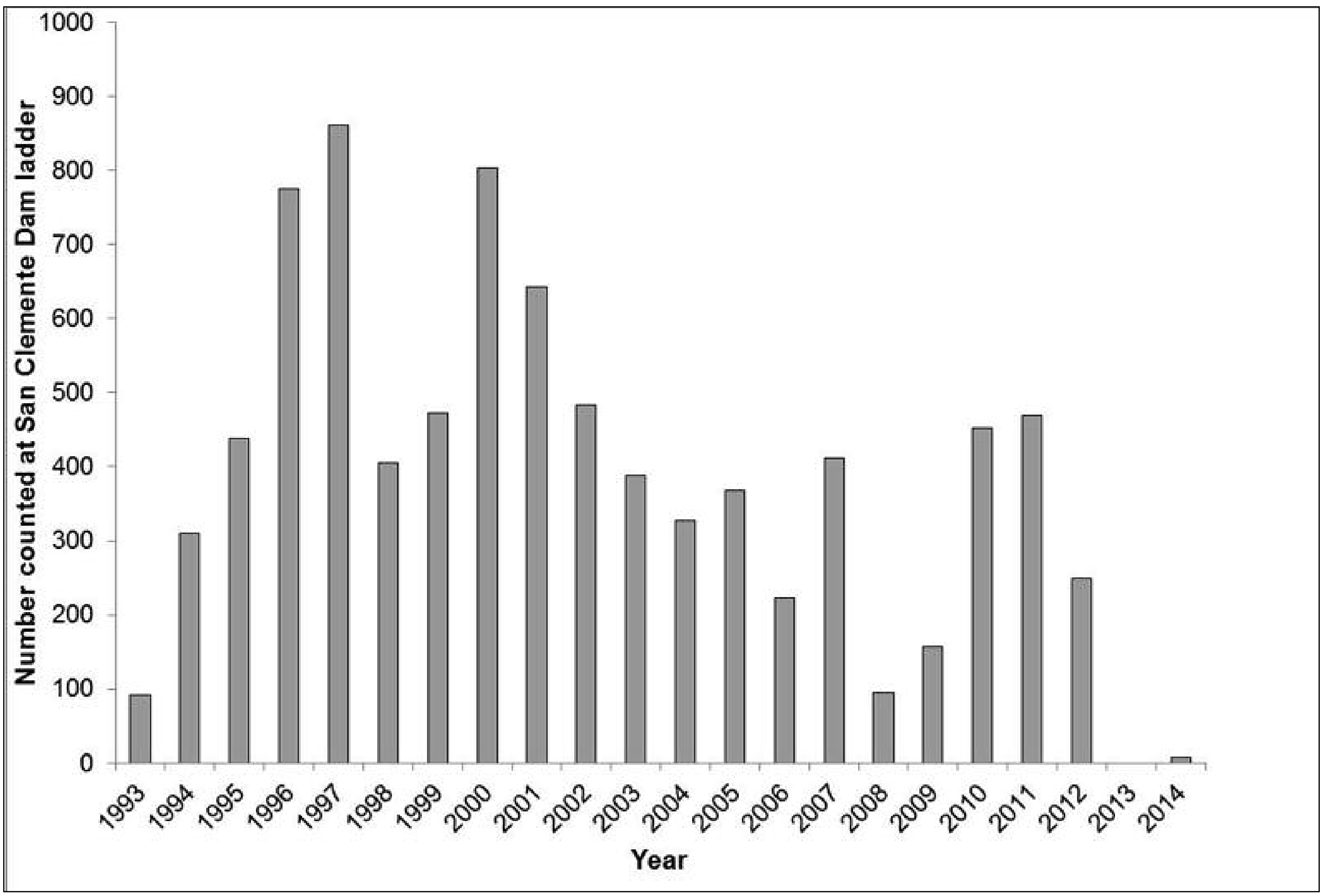

Figure 2. Adult anadromous steelhead trout counted at San Clemente Dam fish ladder, Carmel River, from 1993 – 2014, note year is the cohort year (2014 = fall 2014 = spring 2015). Dam and ladder removed August 2015. Data from Monterey Peninsula Water Management District.

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were also apparent in the way that the area immediately upstream of the re-route channel evolved during winter 2016, with the river downcutting more than a meter through former reservoir sediments that had accumulated since the 1920s. However, the floods of 2017 brought much greater change: when high flows receded, the sediment pulse had reached all the way downstream to the river mouth, with new sediment deposited in every impact reach downstream of the former dam location. The floods introduced new gravels to riffles and pool tails in reaches downstream of dam, which should improve steelhead spawning habitat. The abundance of large wood downstream of the dam location also increased following the floods, resulting in more complex channel habitats. The river channel in the old reservoir reach had widened five-fold, carving an entirely new flow path through the reservoir deposits. These responses differed from those measured in previous large dam removals, as in no previous example had exceptionally high flows followed so soon after dam removal.

We also sampled *O. mykiss* at four reaches before and after dam removal: one control reach, the reservoir reach, and two impact reaches within 2 km of the dam site; all four of these reaches were also surveyed for sediment and channel characteristics. The impact reaches were located in areas where we thought an immediate population response to dam removal was most likely. We found significant variability in fish abundance in the reaches examined, which is common for Pacific salmonids, and likely reflective of the natural variability of such populations. During the course of the sampling from 2013 to 2017, the region experienced an exceptional drought with extremely low flow conditions, including more than a year when the Carmel River surface flows did not connect to the ocean (2014). Added to this were large fires in 2015 and 2016 in the upper watershed, and the extreme flow events in 2017. Against this backdrop of dramatic environmental variability, it is predictable to see fluctuations in fish abundance, diversity of habitat available, habitat use, and fish growth. And indeed the size distribution of *O. mykiss* in the reaches surveyed did vary over the course of the study. In the impact reaches, we observed an increase in the breadth of fish sizes and age classes as these areas of the stream shifted from rather simple, static habitats to much more dynamic and diverse habi-

Fish sampling prior to (above) and following removal of San Clemente Dam, Carmel River, California. Photos by T. Williams

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tats (Figure 3). Untangling the changes resulting from the drought, fires, dam removal, and extreme flow events is difficult, but clearly the absence of the dam starting with the sampling in the fall of 2015 allowed the reservoir impact reach and the downstream impact reaches to experience sediment and channel changes that would not have occurred with the dam in place.

Early indications from our data and other observations are that 1) adult steelhead and Pacific lamprey pass through the re-route channel and access areas upstream of the former San Clemente Dam, and 2) increased size variability of *O. mykiss* in the sampled reaches after dam removal is consistent with observations of more complex and diverse habitat conditions where previously very simplified habitat occurred. We also observed in fall 2017 that *O. mykiss* rapidly colonized the new habitat in the re-route channel. However, as with other dam removals, understanding the response of anadromous Carmel River fish populations will require more than just three years. Carmel River steelhead typically have a generation time of four years, and habitat response in the Carmel River is extremely dependent on events such as high flows, as shown in the first three years since the removal. Expectations of the recovery time scale should be measured both in generation time of steelhead and the temporal dynamics of the physical/ecological processes of the watershed and region.

Dams, with or without fish passage, block or constrain much more than fish, including important habitat-forming processes on downstream reaches. Those interested in salmon and steelhead often focus on restoring access to historically available habitat, which, though critical, is only part of the impact dams have on aquatic systems. Physical and ecological stream environments are extremely dynamic and require periodic inputs of wood, sediment, and periodic disruptive floods to provide their optimal ecosystem function. Regardless of whether we consider the Carmel River in a Mediterranean climate or the Elwha

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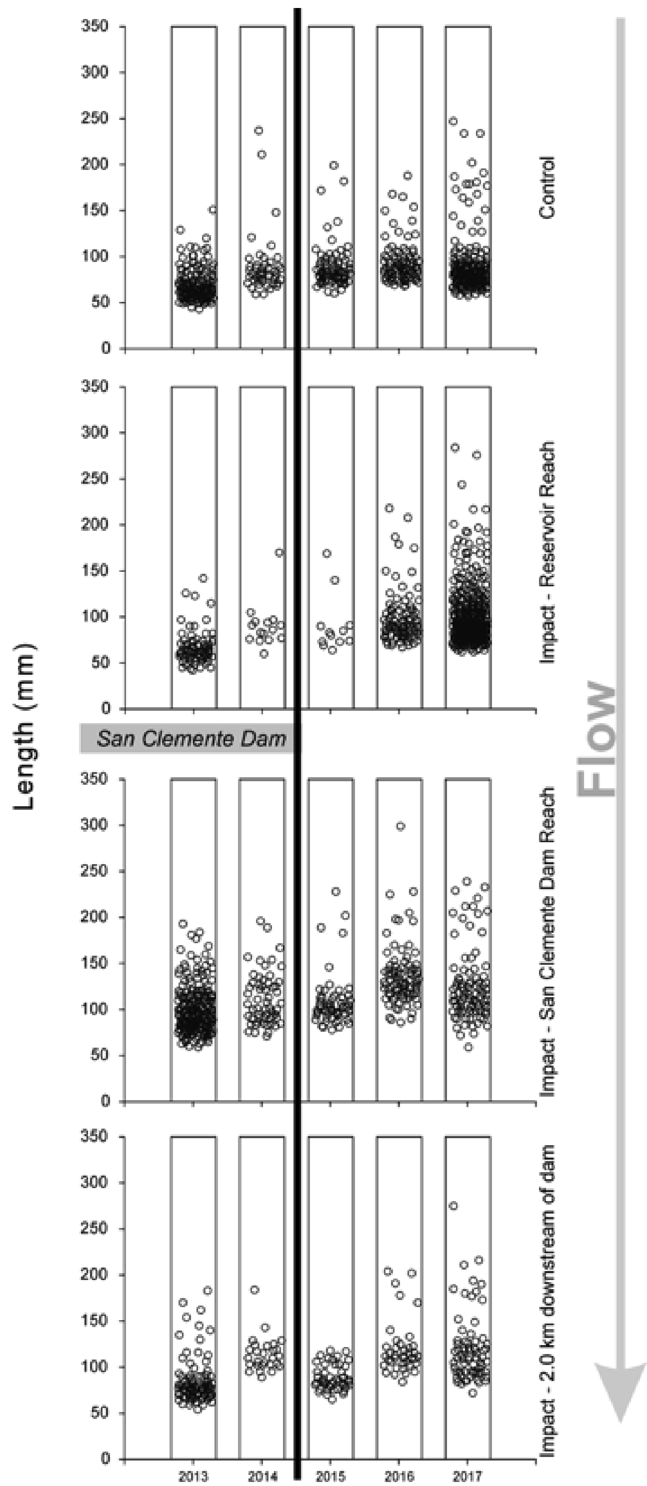

Figure 3. Size distribution of O. mykiss during fall sampling at four BACI study sites sampled on the Carmel River. Each circle is an individual fish. Dark vertical bar between 2014 and 2015 indicates removal of San Clemente Dam.

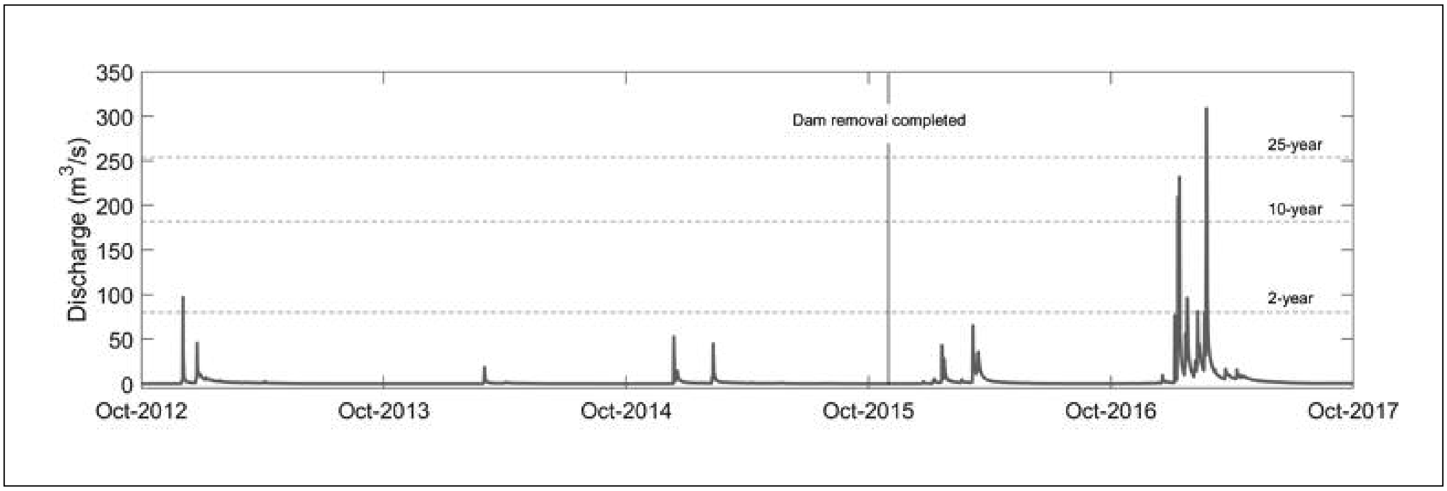

Figure 4. Discharge records during period of study showing high flow events in January and February 2017 (USGS data).

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River in the temperate rainforest of the Olympic Peninsula, the physical and ecological processes that form the habitat template for salmon and steelhead are not static. Restoring the connections within a watershed reduces constraints on physical and ecological processes, allowing dynamic habitat features such as connected floodplains, wood and gravel delivery downstream, and constant rearrangement of sediment, wood, and stream channels. Restoring these and other non-static features of stream systems provides a diverse habitat that allows for future expression of life-history diversity of salmon and steelhead.

On the Carmel River, the floods of 2017, which occurred only 14–15 months after removal of San Clemente Dam, triggered accelerated recovery of physical processes that had been constrained when the dam was in place. Yet, it will take many more cycles of high flow events for the stream to settle into a new dynamic equilibrium. It is on this dynamic template that *O. mykiss* were once abundant and likely much more resilient to the constantly changing conditions along the West Coast and specifically in the Carmel River. To date, the immediate response of the physical processes and the steelhead on the Carmel River to the removal of San Clemente Dam is encouraging. Although additional and significant constraints still confront the watershed and steelhead in the Carmel River, the removal of San Clemente Dam is a large step toward recovering the processes and the habitat critical for recovery of this steelhead population.

Natural flooding accelerated the restoration process, yet it will take many more high flows for the river to settle into a new ecological dynamic.

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San Clemente Dam Removal and Carmel River Reroute Project Website: http://www.sanclementedamremoval.org/

Eelgrass as Vital Nursery Habitat for Young Salmon

By Michael Arbeider and Jonathan Moore

— *Simon Fraser University* —

Dr. Jonathan Moore is an Associate Professor at Simon Fraser University in British Columbia where he is the director of the Cooperative Resource Management Institute and holds the prestigious Liber Ero Chair of Coastal Science and Management. In partnership with diverse collaborators, he and his research team, the Salmon Watersheds Lab (https://www.jonwmoore.org/), work from headwaters to estuaries to inspire conservation actions and inform management decisions.

Michael Arbeider is a M.Sc. student at Simon Fraser University under supervision of Dr. Moore in the Salmon Watersheds Lab. As part of a series of students who have studied the Skeena River estuary, Michael's research focuses on the food web and ecology of juvenile sockeye and coho salmon, Pacific herring, and surf smelt in relation to habitat features. He has contributed to projects on tributary connectivity in the lower Fraser River and assessing our state of knowledge on impacts from oil-sands development on the marine environment.

As scientists who study salmon, we are continually astounded by their truly remarkable migratory life-cycle. Every generation is defined by the one in a thousand individuals that successfully migrates from freshwaters to the ocean and back, through dark and cold waters for potentially thousands and thousands of miles. Across this spectacular life-cycle, they need to eat and grow and avoid being eaten. Here, we take a look at one of the habitats that can support salmon on this life-cycle — that of eelgrass in the nearshore marine ecosystem.

First, let's imagine a salmon-eye perspective of this phase of their journey.

With a shimmering school of her brothers, sisters, and cousins, she makes her way through the dappled light of a small stream, allowing the current to push her downstream. She is shiny, silver and the size of an index finger. The water is cold and sweet with dissolved leaves and rocks. The forest ends and the stream grows sluggish. As the salmon follow the deeper channel through the tide flat, the water below them starts to shimmer with a wedge of saltwater from the ocean.

> ***As its name implies, eelgrass looks like grass, growing up to several feet in length.***

Waves mix the water and, boom, they suddenly are immersed in saltwater. She flairs her gills and coughs. But she is ready for this. Rather than being pickled like a pickle, her gills and kidneys start working overtime to uptake more water and excrete more salt. The ground below her pulses back and forth with the waves above. Small patches of green forests appear in the brightly lit expanse of the tidal flat, swaying in the waves. CRASH! The water concusses and a school of salmon dart in collective reflexive motion, but there is a puff of scales, a splashing flap of wings, and one of her schoolmates disappears in the beak of a kingfisher. The school rushes into the entanglement of flat green fronds. In the swaying forest, she hovers. A shrimp-like amphipod pops up off of one of the blades of seagrass. Dart. Snap. Swallow. Yum! She feels safe near the eelgrass, away from the clear, brightly-lit water. Little schools of young perch drift in clouds above the forest. She will stay here a while, feasting, growing, and adjusting to the new salty water, before continuing out into the dark, deep waters of the Pacific Ocean. Perhaps she will be the one.

Along the Pacific Coast, salmon may encounter eelgrass in small patches and bands along the coast, as well as in large expansive beds in estuaries. Marine eelgrass (*Zostera*) is a perennial flowering plant that grows on sandy banks in estuaries and near shore environments. Along the western coast of North America, eelgrass consist of both a native species (*Zostera marina*) as well as an introduced species (*Zostera japonica*). The native species tends to inhabit low tidal and sub-tidal areas, locations that infrequently get exposed to air during low tides, while the non-native species tends to inhabit slightly more shallow portions of nearshore ecosystems. As its name implies, eelgrass looks like grass, growing up to several feet in length. It can be exposed during low tides and lie flat on the sand like wet stringy hair. When it is covered by water, blades of eelgrass rise up in the water, aided by an adaptation where it regulates the amount of salt in their veins to maintain buoyancy, and sway in the water like a verdant forest pulsing in the wind. Like the trees in a forest that provide shade and control erosion, eelgrass also stabilizes the sediment in which it grows and controls erosion. It also traps nutrients from river flow by filtering and slowing down the dissolved organic matter or nutrients (broken up leaves or insects for example) that has accumulated from kilo-

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meters upstream. These nutrients may in turn be absorbed by the layer of algae that grows on the blades of eelgrass and by bacteria in the soil. The algae, bacteria, and the eelgrass itself, provide food for a variety of amphipods and copepods (tiny shrimp-like critters that range from the size of a grain of sand to a bean) that are key food sources for small fishes like young salmon.

Scientists are building understanding of the ways that eelgrass habitats support salmon. For example, a series of studies in the Nanaimo estuary of Vancouver Island, British Columbia, Canada, found that eelgrass plays a key role in the food webs that support migrating juvenile chum and ocean-type (age 0) Chinook smolts. In 1979 Michael Healey, a Department of Fisheries and Oceans scientist, found that the productivity of the primary prey, a crunchy genus of copepods called Harpacticoids, was probably just enough to support the 2-4 million chum that migrate every year on their way to the ocean. However, this estimate was made with samples that were not taken from eelgrass habitat. Subsequently in 2016, an MSc student from the University of Victoria, Laura Kennedy, found that the production of the primary prey for both chum and Chinook was much greater in eelgrass patches than in other estuary habitats. Her work suggests that eelgrass is an essential component in supporting the overall food web, possibly reducing starvation risks and competition between salmon that was originally implied by Dr. Healey. Other studies have focused on the other aspects of the relationship between eelgrass and salmon. For example, Brice Semmens, a PhD student at the University of Washington, performed a study in 2008 where he tagged juvenile Chinook salmon with little transceivers in Willapa Bay of Washington at a nearshore site that contained both native and introduced species of eelgrass, oyster beds, and mud flats. He discovered that young Chinook salmon preferred to spend time in native eelgrass habitat compared to locations such as over the oyster farm or open mud flat or the shallower non-native eelgrass. In addition, he found that fish were more likely to survive the longer they spent in eelgrass (likely due to being able to hide from hungry kingfishers!). Thus, as scientific understanding builds, it appears that eelgrass habitats can be quite important to young salmon through providing shelter as well as food.

The importance of eelgrass habitat for young salmon likely varies across the diversity of salmon species, life-histories, and locations. Some salmon, like juvenile Chinook, spend up to months in estuarine and coastal habitats and may use the protective frond forests of eelgrass more than other species. But some life-history types of Chinook, such as those who spend 1-2 years in freshwater first, are not strongly connected to the food web of eelgrass because they primarily eat pelagic species that are not associated with eelgrass productivity. Whereas juvenile pink salmon are on the other end of the spectrum; they may spend very short amounts of time (days or less!) near areas with eelgrass but feed heavily on the crunchy copepod species that are highly abundant in eelgrass beds. In addition, different eelgrass locations may play different roles for salmon. Some populations may not rely strongly on eelgrass and different eelgrass habitats likely vary in importance. Instead of making blan-

Flora Bank eelgrass at low tide looking like wet hair. Cockle in the foreground and scientists in the back. Photo by Jonathan Moore.

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ket statements about the benefits of eelgrass for all salmon, it is more scientifically accurate to consider eelgrass as one of many potentially important habitats that salmon rely upon across their vast journey.

However, eelgrass beds and estuaries are increasingly among the most degraded ecosystems around the world. Estuaries are often under heavy development pressure because protected embayments are optimal locations for ports, and the surrounding land can be particularly productive for farming or sought after for urban development. As human populations continue to grow, so do their potential cumulative impacts on eelgrass and nearshore ecosystems. Shoreline and port development increasingly shades out or destroys eelgrass beds through physical structures and dredging. Maintaining shipping traffic also requires periodic dredging, which can prevent eelgrass from re-establishing and also increases turbidity that can shade or smother eelgrass in the surrounding area. Even the anchors of small recreational boats can rip up little chunks of eelgrass. Clam aquaculture also has the potential to dig up big chunks of eelgrass if it is not legally protected. Another threat to eelgrass is eutrophication — the process when excess nitrogen and phosphorous promotes growth of algae that outcompetes and shades eelgrass. Excess nutrients can come from sources like farms that are far upstream, untreated sewage, and even aquaculture like fish farms. On top of this, warmer summer waters hinder eelgrass productivity, and there are increasing reports of eelgrass wasting disease, which is caused by a slime mold associated with warm ocean temperature. Climate change and associated sea level rise are further emerging threats. However, in the range of Pacific salmon, the status of eelgrass habitat has more bright spots. Eutrophication problems are not as rampant along many parts of the West Coast of North America and there is generally more protection of eelgrass.

Burgeoning coastal development continues to test whether environmental legislation and decision-makers do indeed protect important salmon habitats of coastal ecosystems. The recent proposed industrial development at Flora Bank in the Skeena River estuary of British Columbia, Canada is one example we have direct experience with. Flora Bank is a large sandy expanse that supports the largest eelgrass bed in the greater Skeena River estuary, but was also the proposed location of a large liquefied natural gas terminal and associated fueling pipeline. Research by our research group at Simon Fraser University, in collaboration with Skeena Fisheries Commission and Lax Kw'alaams Fisheries, discovered that this location was particularly important to migrating young salmon. In particular, our field sampling discovered that there were many times more salmon on and near Flora Bank compared to other locations in the estuary, including other eelgrass habitats. These research findings elevated concerns regarding the potential negative environmental impacts of this proposed project. Despite these concerns over risks to eelgrass and salmon, Canada's federal government approved the project with conditions. Recently, the proponent withdrew from this project given mounting project costs, falling market prices, and on-going opposition from local communities. An article in the January 2017 issue of *The Osprey* examined this conservation battle in more detail. This example highlights the continued need for engaged stakeholders to continue to give a voice for salmon and salmon habitats like eelgrass.

Eelgrass beds and estuaries are among the most degraded ecosystems around the world.

Two species of juvenile salmon swimming together in the eelgrass frond forest of Flora Bank. Photo by Tavish Campbell, SkeenaWild Conservation Trust.

Eelgrass and all other habitats can be protected through policy and planning, and it can be restored at previously impacted sites. Best practice policies ultimately incorporate an analysis of the cumulative effects of all pathways that are impacting ecosystems. This means, for example, that when a new structure is going in or increased port traffic is being considered, it is crucial to take into account all the effects of existing projects and combine them with what the additional effects from the new project are.

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In order to understand the degree to which projects pose risks to eelgrass, it is important to understand the degree to which the damage to eelgrass could be undone or mitigated. On the one hand, there is building scientific evidence that if eelgrass beds are damaged such as by scour or disturbance, then restoration efforts can often be successful. In an intensive process, eelgrass shoots, roots, or seeds are hand-planted like a forest is replanted with seedlings after it is harvested. The building body of science (see references below) suggests that replanting can be successful, giving support for eelgrass recovery efforts. On the other hand, proponents of developments may justify the permanent destruction of eelgrass by claiming they can mitigate this loss through the creation of equivalent eelgrass habitat elsewhere. From a scientific perspective, habitat mitigation of eelgrass has three main problems. First, creation of eelgrass habitat elsewhere will transform habitat in another location, which may have actually already been providing important habitat to a variety of species. Second, attempts to create a new patch of eelgrass in a location for which one does not already exist are likely to fail — eelgrass does not thrive in all environments and there is likely a reason why there was not already an eelgrass bed there. Third, if a new eelgrass habitat is successfully created elsewhere, then there are still no guarantees that it will provide the same value given it is located in a different place. Thus, it is our scientific opinion that claims of mitigation of eelgrass destruction by developers should be viewed with skepticism.

If you want to contribute to the protection of habitats like eelgrass for salmon, there are many potential opportunities for engaged citizens and stakeholders. Be attentive for new proposed developments in estuaries, bays, and nearshore environments and contribute in their public consultation processes. Investigate if your local sewage system is being treated and write letters to your city council if it is not. Contribute to regional planning processes and organizations that are charting a vision for development and protection of coastal habitats. Vote. There are also good resources and opportunities to learn more about eelgrass. For example, the National Oceanic and Atmospheric Administration hosts an interactive map called ShoreZone (shorezone.org , also accessible through coastalandoceans.com/Core-Services/Imaging/) where you can see photos, flights, and data layers with information on where eelgrass has been mapped. If you want to experience eelgrass habitats firsthand, put on a wetsuit and mask or hop in a kayak (be careful), and float above the waving eelgrass and imagine small salmon in the waters around you (or possibly see them yourself!). Perhaps there are also opportunities to build the community of people who appreciates this part of the salmon journey. For example, up in the Skeena River watershed there is the annual “Invisible Migration Celebration” (http://skeenawatershed.com/migration); an aptly-named event that brings communities together to bear witness to the spring migration of the millions of young salmon from the headwaters down to the estuary. Thus, there are many different ways that interested stakeholders and citizens could contribute to conservation efforts of salmon habitats like eelgrass.

If you want to help protect eelgrass habitat, there are many opportunities for engaged citizens.

While the life-cycle of salmon starts and ends in the sparkling gravel of cold and clean streams, rivers, and lakes, salmon rely upon a series of potentially underappreciated habitats in between — cold oceans, beaver ponds, deep pools with shade and stumps, cold groundwater that sneaks through the rocks, salt marshes, and eelgrass beds. Protection and management of these habitats will be foundational components of effective conservation efforts towards thriving salmon.

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On the Evolution and Conservation of Summer Steelhead and Spring Chinook

By Tasha Thompson, Michael Miller, Daniel Prince and Sean O'Rourke

— University of California, Davis —

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Advances in genomics technologies, the methods we use to examine DNA, are revolutionizing our understanding of biology in organisms ranging from humans to microbes. For ecologists and conservationists, these advances can provide unprecedented levels of information about evolutionary relationships between species or populations, the genetic health of populations, and the genetic underpinnings of important adaptive traits. However, advances in technology have outpaced advances in conservation policy, and it remains unclear how these novel insights will be integrated into conservation practices. Our recent paper entitled "The evolutionary basis of premature migration in Pacific salmon highlights the utility of genomics for informing conservation" examines the genetic and evolutionary basis of adult migration timing (a.k.a. run timing) in coastal populations of steelhead and Chinook salmon. (The paper is available for download at: https://doi.org/10.1126/sciadv.1603198.) Our study revealed that variation in a single gene explains the difference between early and late migrating populations. Furthermore, the early run genetic variants of this gene only evolved once in each species. These results provide an example of how genomics can be used to inform conservation and indicate that current conservation policy can be insufficient to protect significant biodiversity and ecosystem services.

Like other Pacific salmon species, steelhead and Chinook are born in freshwater streams, migrate to the ocean as juveniles, spend a few years at sea, then return to the stream they were born in to spawn. Both species exhibit two strikingly distinct life history types when it comes to spawning migration time. Late or "mature" migrators (a.k.a. fall Chinook and winter steelhead), return from the ocean in a sexually mature state, migrating directly to their spawning grounds and spawning almost immediately. In contrast, early or "premature" migrators (a.k.a. spring Chinook and summer steelhead) return to freshwater months before sexual maturity. These fish migrate high into the watershed and hold in cold, deep pools over the summer while their gonads develop, then spawn at a slightly earlier (though overlapping) time compared to their mature migrating counterparts.

> *Spring Chinook and summer steelhead are declining while fall and winter spawning populations remain relatively healthy.*

To reproduce successfully, premature migrators must have enough energy to not only survive in freshwater over the summer, during which time they do not eat, but also to develop their gonads in preparation for spawning. Premature migrators do this by storing excess fat prior to migration that will subsequently be used for maintenance and sexual development during the summer, and therefore, premature migrators have much higher fat content during migration than their mature migrating counterparts. Thus, not only do premature migrating populations provide additional fishing opportunities due to their distinct migration time, but premature migrators are also more coveted (and tasty) because of their high fat content. Given these attributes and their role as an important food source following winter, it is not surprising that premature migrating populations played a special role in the cultures and traditions of the indigenous peoples of the Pacific Northwest and Northern California. For example, indigenous peoples in the Klamath Basin in Northern California celebrated the return of spring Chinook with ceremonies that progressed upriver with the salmon migration.

The evolutionary advantage of premature migration — in other words, the reason premature migration exists — is that it allows premature migrators to utilize spatial and temporal habitat that is difficult for mature migrators to access. For example, migrating in the early summer allows summer steelhead to utilize habitat above barriers that are difficult to ascend during high winter flows. In Chinook, migrating in the late spring prior to harsh lower river conditions allows spring Chinook to spawn earlier and higher in the watershed than fall Chinook, which must wait for rains and cooler water temperatures before migrating to the spawning grounds. In

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both cases, the premature migration of adults provides a competitive advantage by giving their offspring access to exclusive habitat that offsets the difficult over-summering conditions premature migrating adults face. The fact that premature migrators utilize distinct habitat also has important ecological consequences, because they carry marine-derived nutrients into locations that mature migrators do not reach.

Despite their multifaceted importance, spring Chinook and summer steelhead — premature migrators — have been extirpated or are in decline across most of their range while fall Chinook and winter steelhead populations — mature migrators — remain relatively healthy. Human actions such as dam building, mining, and logging cause grossly disproportionate impacts to premature migrating populations because of their extended time in freshwater and reliance on headwater habitat. However, because previous genetic analyses have revealed that, in most cases, premature migrating fish are closely related to mature migrating fish within the same river, conservation policy typically lumps them into the same conservation unit, referred to as an evolutionarily significant unit (ESU) or distinct population segments (DPS), depending on the species. So, despite the extirpation or substantial decline of premature migrating populations, the ESUs or DPSs to which they belong usually retain relatively healthy mature migrating populations and thus have low extinction risk overall. The consequence of this is that spring Chinook salmon and summer steelhead, in most situations, don't receive special conservation protections despite sharp declines.

The goal of our recently published study was to investigate the genetic and evolutionary basis of premature migration and explore potential consequences of not independently protecting this noteworthy and beneficial adaptation. Ultimately, we found that incredibly important genetic adaptations (e.g. premature migration) can rely on rare evolutionary events in single genes, and that current conservation policies can fail to protect this type of adaptive variation. Most current policies protect genetic adaptations between distantly related population units, but they don't necessarily protect adaptations within closely related population units, and the consequences of that can be substantial: in the case of Chinook and steelhead, the consequences could be the permanent loss of an economically, culturally, and ecologically important life history. To account for this type of adaptive variation, current conservation policies will likely need to be improved.

Policies that lump together premature and mature populations have been justified by two assumptions that arose from previous low-resolution genetic analyses. The first was that spawning migration time is controlled by many genes that each has a small effect. The second was that spring Chinook and summer steelhead had evolved from their mature migrating counterparts independently in each river. These assumptions led to the belief that premature migration had evolved many times and therefore could easily re-evolve in the future if lost. Our study, which used new high-resolution approaches, shows these assumptions were incorrect.

To identify the genetic basis of migration type, we used an inexpensive and efficient technology called RAD (restriction-site associated DNA) sequencing to test hundreds of thousands of positions throughout the steelhead genome, and then compared the results of summer steelhead to the results of winter steelhead to see where their genomes differed. This steelhead analysis included samples from Scott Creek, just north of Santa Cruz, California, the Eel, New (a tributary of the Trinity), North Umpqua, Siletz, and Klickitat rivers. We then conducted a similar analysis with spring and fall Chinook using samples from the Eel, Trinity, Salmon (a Klamath River tributary), Rogue, Umpqua, Siletz, Puyallup, and Nooksack rivers. Strikingly, we found that the same genomic region differed between summer and winter steelhead as between spring and fall Chinook, and that variation in this single region (a gene called GREB1L) appears to completely explain the difference between migration types in both species.

Premature spawners like this wild spring Chinook salmon on a spawning bed in Oregon's McKenzie River are suffering greater population losses than their fall and winter spawning counterparts. Photo by Jim Yuskavitch

After discovering the premature migration gene, we wanted to understand the evolutionary process that produced the premature migration versions in this gene. When organisms reproduce, they generate copies of their DNA that go into their gametes (i.e. sperm or eggs). Although the process of DNA replication is extreme-

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ly accurate, there are billions of positions in the DNA that need to be replicated — so many that a handful of random mistakes typically occurs during the replication process. These mistakes, called "mutations", are then present in the DNA of the offspring and provide the genetic variation on which selection. To do this, we reconstructed the evolutionary history of the GREB1L gene by looking at the patterns of DNA sequence variation across our samples. Strikingly, we found that all summer steelhead versions had arisen from a single event and all spring Chinook salmon versions had arisen from a single event.

Premature spawning evolutionary strategy allows those fish to utilize habitat, such as this river in Idaho's Sawtooth Mountains, that may not be accessible to mature spawners that spawn shortly after entering freshwater. Photo by Jim Yuskavitch

evolution can act. The overwhelming majority of mutations are either benign or have a negative effect on the offspring's characteristics. However, it also possible for these mutations to produce novel characteristics that are beneficial in terms of survival and reproduction. In this case, the offspring will reproduce at a higher rate relative to other members of the population and pass this new beneficial mutation to their own offspring. This process of a particular genetic variant producing disproportionate reproductive success is known as positive selection. With positive selection, even though a mutation originates in a single individual, its frequency in the population can rapidly increase.

We wanted to understand if the premature migration genetic variants in different rivers arose from independent mutational events or were the product of a single mutational event that subsequently spread through a combination of straying and positive

The mutational events were different between the species, so both occurred sometime in the past 15 million years since the two species diverged from each other. Finding that the same gene is crucial for premature migration in two separate species and that all the premature migration versions of this gene we examined arose from a single mutational event within each species strongly suggests that the genetic mechanisms for evolving premature migration are limited and happen very rarely across evolutionary time.

For the Pacific Northwest and Northern California, our study indicates that we should be much more concerned about the decline of spring Chinook and summer steelhead than we previously were. The premature life history depends on a particular version of the GREB1L gene, but the number of fish carrying that version has declined dramatically. Premature migrators have been completely lost from many rivers where they used to be abundant, and most populations that remain are severely depressed. For example, the Salmon River in California only had approximately 100 spring Chinook return this year, where it historically had tens of thousands. This pattern is common throughout California, Oregon, and Washington. If premature migrating fish are lost, that version of GREB1L will be lost and may take many thousands to millions of years to re-evolve.

Identifying the premature migration gene has also allowed us to develop genetic markers to easily test the migration type (premature or mature) of ambiguous samples such as juveniles or carcasses for which the migration type was not previously able to be determined. This will expand our understanding of the ecology of premature versus mature migration, factors behind the decline of premature migrators, and steps that can be taken to bolster premature populations. For example, testing juveniles at fine-scale spatial resolution throughout a watershed will allow for a precise understanding of differences in habitat utilization between premature and mature migrators, providing information for habitat restoration efforts.

Now that genomic technologies allow us to determine the genetic basis and evolutionary history of important adaptations, we can use this information to improve conservation policies. More specifically, we can better protect adaptations that exist within closely related population units, are disproportionately impacted by human activities, and are unlikely to re-evolve in human timeframes. In these cases, the development of a conservation framework that supplements current ESUs and DPSs by protecting specific adaptive variation will be necessary to prevent the loss of significant biodiversity and ecosystem services.

For more information see:

Prince DJ, O'Rourke SM, Thompson TQ, Ali OA, Lyman HS, Saglam IK, Hotaling TJ, Spidle AP, Miller MR. (2017) "The evolutionary basis of premature migration in Pacific salmon highlights the utility of genomics for informing conservation." *Science Advances*. 3(8):e1603198.

The Fish That Got Away

Puget Sound Farmed Atlantic Salmon Escape a Wake-Up Call for Wild Salmon and Steelhead Advocates

By Jim Yuskavitch
— Editor, The Osprey —

Author Jim Yuskavitch is editor of The Osprey.

Wild salmon advocates got another wake up call to the hazards of industrial Atlantic salmon farming along the Pacific Northwest coast when as many as 160,000 farmed fish escaped from a damaged net pen in Puget Sound off Washington State last August 19. The pen, one of ten operated by Cooke Aquaculture Pacific, a Canadian company, was located at its Cypress Island farm and contained more than 300,000 Atlantic salmon.

Atlantic salmon are legally classified as a 'pollutant' by the state of Washington and the escape was quickly labeled a disaster by the indigenous Lummi Nation, which launched an emergency effort to catch as many of the fish as possible, harvesting about 20,000 fish totaling approximately 200,000 pounds over the days following the net pen breach. By the end of September recreational anglers had caught another 2,000 or so Atlantics in Puget Sound, north to Vancouver Island and south to the mouth of the Columbia River, while state officials worked to see that the broken net was repaired before any more fish took a powder.

The immediate concern was that a mass escape of non-native Atlantic salmon could swamp native Pacific salmon and steelhead streams, competing with struggling wild fish for food and habitat, and even worse, potentially even establishing reproducing populations of their own — a nightmare scenario for wild, native fish advocates. Farmed Atlantic salmon have escaped from net pens off the Washington Coast in the past. Between 1996 and 1999, a total of nearly 600,000 Atlantic salmon broke out of their pens in three different escapes. Fortunately, the foreign fish apparently caused no damage to wild, native salmon and steelhead runs.

> *Wild fish advocates have been battling the Atlantic salmon farming industry on the West Coast for years with little success.*

Nevertheless, there is a long list of reasons why Atlantic salmon farming on the West Coast is of grave concern to conservationists. First, feces and other waste products associated with raising farmed fish flow out of the net pen to pollute the surrounding ocean environment. Second is the inefficiency of producing protein by this method that requires harvesting large amounts of ecologically valuable forage fish to manufacture food for the salmon. Almost four-and-a-half pounds of forage fish are needed to produce a little over two pounds of farmed Atlantic salmon. Third are disease outbreaks driven by large numbers of fish being held in concentration such as the major outbreak of Infectious Hematopoietic Necrosis in net pens near Bainbridge Island in 2012. In addition, salmon farms don't always bring the promised jobs and prosperity to coastal communities.

But the most concerning threat to wild Pacific salmon and steelhead posed by Atlantic salmon farming off the Pacific Northwest coast is the danger of increased infection of wild fish by sea lice through the vector of farmed salmon. A tiny marine parasite, sea lice don't typically cause adult salmon and steelhead much trouble. But for young fish, it's a different story, and investigations by Raincoast Research have found that just a few sea lice can kill juvenile Pacific salmon. Since salmon farms are usually located in protected bays and inlets, which are often near the mouths of rivers, out-migrating juvenile salmon may swim near or directly through net pens filled with salmon that could have sea lice, becoming exposed to being parasitized themselves. Another study determined that a dozen Atlantic salmon farms off the coast of British Columbia — which now has about 85 farms — produces more that a billion sea lice eggs just prior to the out-migration of juvenile pink salmon.

While wild fish advocates have been battling the Atlantic salmon farming industry off the Pacific Northwest coast for years, it's been an upstream battle against a politically influential industry that has become well established in North America. Today, Atlantic salmon farms off the coast of British Columbia produce about 100 million pounds of fish flesh each year, while farms off Washington State's coast contribute another 10 million pounds.

However, some positive action has resulted from last summer's escape of Atlantic salmon into Puget Sound.

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Washington State has terminated Cooke Aquaculture Pacific's lease to operate their farm at Port Angeles, which currently has almost 700,000 Atlantic salmon in its net pens. After the August 2017 escape, the State of Washington ordered an inspection of all of the company's farms along the coast, discovering that the Port Angeles farm had pens outside the boundaries of its lease with the state that also posed a potential navigation hazard, along with some facilities maintenance problems. In addition, two Washington State lawmakers, Republicans Drew MacEwen and Jim Walsh have introduced legislation that would immediately ban Atlantic salmon net pen farming in Puget Sound, while another bill offered by Democratic state senator Kevin Ranker would phase them out over the next seven years as their leases expire. These bills will be considered when the Washington State legislative session begins in January 2018.

On the legal front, the Wild Fish Conservancy has filed a lawsuit against Cooke Aquaculture Pacific for negligently allowing the release of Atlantic salmon into public waters, charging that it is a violation of the National Pollutant Discharge Elimination System permits under which the company is legally obligated to operate. The Wild Fish Conservancy has also launched a campaign called "Our Sound, Our Salmon," to oppose expansion of Atlantic salmon farms in Puget Sound, noting that California, Oregon and Alaska have already banned salmon farming in waters off their coasts.

There continues to be active push-back against Atlantic salmon farming in British Columbia as well, where last November First Nations groups held a protest at a Marine Harvest Canada farm off the north coast of Vancouver Island over their concerns about the potential impacts on wild salmon. The British Columbia government has not issued a permit for any new Atlantic salmon farms since 2015 and is now reviewing its licensing and aquaculture policy.

Atlantic salmon are a valuable and noble game fish that needs protection, however they have no business being farmed on the West Coast far from their native range. Photo by Jim Yuskavitch

The Atlantic salmon farming industry on the West Coast has successfully weathered criticisms from conservationists for decades. But ultimately, the 2017 mass escape might turn out to be a blessing in disguise if it eventually leads to banning net pens in Puget Sound, and as wild fish advocates in British Columbia continue to put pressure on both the industry and BC government, changes for the better may eventually come there as well.

Guest Column
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salmon habitat, including Bristol Bay. Many Alaskans understand that there's nothing so powerful as the intact landscapes and river systems that still exist there as nowhere else. That's why locals endure harsh winters and rugged conditions year round. That's why many of us make annual angling pilgrimages there.

If we can hold fast to and collectively rally around the idea of whole, productive landscapes, we may actually pass something worthwhile on to the next generation.

For more information on the Alaska salmon coalition, visit StandforSalmon.org.

Bristol Bay's tremendous run of valuable sockeye salmon would be seriously threatened by the proposed Pebble Mine. Photo courtesy US Environmental Protection Agency.

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