Benefits of Tributary Habitat Improvement in the Columbia River Basin

Results of Research, Monitoring and Evaluation, 2007-2012

BONNEVILLE POWER ADMINISTRATION

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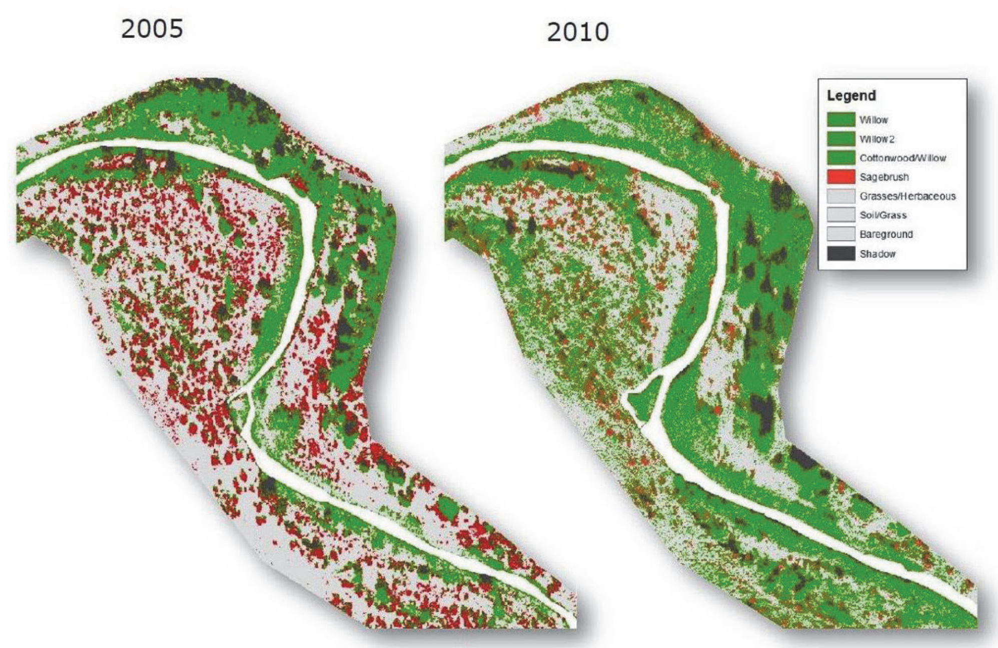

Improved habitat and fish abundance on Bridge Creek

Aerial images reveal expansion of riparian vegetation (in green) along Bridge Creek, a tributary of the John Day River and part of an Intensively Monitored Watershed under the Research, Monitoring and Evaluation program. Habitat improvement actions in 2009 assisted beavers in constructing ponds, raising the water table and restoring more natural stream dynamics and native plants. Research also found significant increases in the percentage and depth of pools that provide refuge for fish and in the abundance and survival of juvenile steelhead.

Contributors

Much of this report was drawn from the many past reports, documents and journal articles listed in the references and, for the most recent results and data, from communication and correspondence with researchers and project sponsors across the Columbia River Basin. The most significant contributors include, in alphabetical order:

Tim Beechie, Northwest Fisheries Science Center

Chris Jordan, Northwest Fisheries Science Center

Tracy Hillman, BioAnalysts, Inc.

Tim Fisher, Fisher Fisheries, Ltd.

Jennifer O'Neal, TetraTech

Charlie Paulsen, Paulsen Environmental Research, Ltd.

Phil Roni, Northwest Fisheries Science Center

Bonneville Power Administration

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Q&A

What is the role of research, monitoring and evaluation (RM&E) in the Biological Opinion for the Federal Columbia River Power System?

The Biological Opinion relies on an aggressive program of RM&E to track the progress of mitigation measures and to improve their effectiveness over time. In terms of tributary habitat improvements, RM&E is designed to better characterize the nature of the connection between fish and habitat so managers can advance habitat improvement actions that will most benefit fish.

What has RM&E revealed about the relationship between fish populations and habitat?

Several studies and analyses have demonstrated significant relationships between habitat and fish populations on large and small scales. Some have estimated the percentage improvement in juvenile fish survival correlated with habitat projects in and near rearing streams. While the best available information indicates that improved habitat benefits fish, RM&E in the Columbia Basin is seeking to describe and quantify the benefits with additional precision to evaluate progress under the Biological Opinion.

How has RM&E helped identify limiting factors?

By confirming or establishing connections between fish and individual habitat metrics such as gravel availability, RM&E helps identify those habitat qualities most closely associated with fish populations, indicating potential limiting factors. Research in the Wenatchee subbasin, for example, shows that fish density drops sharply amid high velocity water that is less hospitable to juvenile fish. That suggests that the availability of slow-water refugia for juvenile fish may be an important limiting factor that could be addressed through habitat improvements. The details of such relationships between fish and habitat quality helps biologists locate habitat projects where they are most likely to support fish.

What does RM&E tell us about the most effective types of habitat improvement actions?

Reviews of the scientific literature and initial results of project effectiveness monitoring have identified fish passage improvements, in-stream wood and rock structures, livestock grazing controls, connection or construction of off-channel habitat and flow augmentation as among the most proven forms of habitat improvements, with the most rapid responses. Other habitat actions such as riparian plantings also have benefits, but take longer to yield clear responses.

Executive Summary

The program of research, monitoring and evaluation that tracks and evaluates habitat improvements for salmon in the tributaries of the Columbia River is one of the largest and most sophisticated of its kind, spanning four states and scores of watersheds and involving many scientists. It is an ambitious initiative to document and measure the benefits of habitat improvements, a keystone of salmon and steelhead recovery, with a degree of detail and precision rarely attempted before. The results will inform management decisions, helping shape more effective habitat projects and strategies.

Site-specific and large-scale studies are now confirming the scientific basis for protecting and improving habitat to promote salmon and steelhead survival and abundance. The evidence does not come from a single study, but rather from the increasing weight of the literature supported by a rapidly expanding body of research and data on hundreds of habitat actions throughout the Columbia Basin. Research has established relationships between habitat quality and fish survival and is pinpointing those factors, such as water flows; the number, depth and proportion of pools; gravel sizes; and temperature; that most influence juvenile salmon numbers. An understanding of those relationships, combined with detailed watershed and population assessments, helps biologists target the most critical habitat issues and more accurately estimate the benefits for fish. Managers can then better focus time and resources where they will make the most difference.

Key RM&E findings so far include:

- Identifying those habitat attributes most closely correlated with fish numbers and most likely to influence them. While the attributes vary by species and area, the findings help focus resources on habitat actions – creating slow-water refuges, for instance – most likely to translate into more fish.
- Showing that habitat actions create the expected improvements for juvenile and adult fish, with the clearest benefits from barrier removals, reconnection of side channels and other habitat actions that correct physical and biological impediments.
- Detecting positive fish responses to habitat actions. Salmon and steelhead have quickly returned to reopened habitat, spawned in greater numbers in restored reaches and increased in abundance following treatment.
- Unraveling relationships between habitat conditions and fish response. For instance, studies in the upper Grande Ronde River Basin indicate that large wood in streams positively affects juvenile Chinook salmon density directly, but also indirectly through the role wood plays in pool formation. These relationships also depend upon the position of a site in a watershed.
- Demonstrating that the RM&E program can accurately measure environmental changes from habitat improvements and resulting increases in fish survival, reporting them in formats that inform managers and improve project design.
- Using RM&E results to better estimate the benefits of new habitat treatments, informing an adaptive management approach that prioritizes investments towards the most effective future actions.

Research has found that habitat improvements can increase fish productivity in a range from a few percent to several times over, depending on the circumstances and scale. An early review of several studies of western streams found an average 123 percent increase in density of juvenile salmonids in rehabilitated reaches. An 2010 analysis of 211 stream rehabilitation projects found a 167 percent average increase in salmonid density following in-stream improvements, although the results varied by species. Studies of juvenile Chinook salmon from the Snake River Basin found 13 percent higher survival among fish from relatively undisturbed habitat relative to fish from recently burned or logged areas, indicating that protection of high quality habitat is an important tool in promoting fish survival. Examination of habitat improvements in the Snake River Basin documented an approximately 20 percent average increase in parr-to-smolt survival associated with large numbers of habitat actions. Taking the analysis a step further demonstrated that the benefits of habitat improvements carry through to adult fish, with more than 50 percent higher survival among adult fish that originated in areas with numerous habitat improvements compared to fish from areas with few improvements.

The increased survival attributed to habitat improvements complements the significant improvements implemented at hydroelectric dams. Both are a necessary focus of the BiOp, with habitat actions essential to salmon recovery since many salmon populations require improved egg-to-smolt survival in spawning and rearing streams. That demonstrates the utility of investments in habitat projects following years of improvements at the dams that have advanced survival at each dam into the range of 93 to 96 percent, and beyond in some cases.

Science provides few absolutes; no single study will provide the definitive proof that habitat is the key to protecting and rebuilding salmon. However, the weight of existing literature, study results and monitoring at many spatial scales combined with the emerging results of experimental studies in the Columbia Basin demonstrates that habitat improvements are targeting and addressing degraded conditions and that fish are responding through increased survival, density and abundance. The results also provide confidence that the comprehensive RM&E program can detect and gauge improvements in habitat conditions and fish populations.

1. Background

Habitat improvements for salmon and steelhead in the Columbia River Basin make up one of the largest habitat rehabilitation programs in the nation, if not the world. The program encompasses hundreds of projects across four states; numerous state, tribal and local partners; and more than $100 million in annual funding. The miles of tributary river and stream habitat restored now exceed the combined length of the Columbia and Willamette rivers. All major fish protection and recovery plans in the basin emphasize habitat improvements to help restore fish and offset the impacts of federal dams. These include the Northwest Power and Conservation Council's (Council) Fish and Wildlife Program and the 2008/2010 Biological Opinion for the Federal Columbia River Power System that outlines protections for fish listed under the Endangered Species Act.

NOAA Fisheries issued the Biological Opinion, conventionally known as the FCRPS BiOp, while the U.S. Army Corps of Engineers, Bureau of Reclamation and the Bonneville Power Administration – the Action Agencies – fulfill its directives.

A life-cycle approach

Habitat is just one component of the Biological Opinion, which pursues an "All-H" strategy of improvements at hydroelectric dams, hatcheries and in harvest, as well as habitat. The strategy recognizes that salmon and steelhead rely on many environments as they grow and mature – from spawning streams to the ocean, each with its own survival challenges. Improvements at dams represent the core of the BiOp, which sets performance standards for the percentage of juvenile fish that pass each dam safely. Recent testing indicates that the dams are on track to meet or exceed the performance standards, which were so ambitious that some originally questioned whether such high passage rates were possible. The BiOp recognizes that improvements at the dams cannot fully mitigate their impacts and looks to management of predators, harvest and hatchery reforms and habitat actions in the tributaries and estuary of the Columbia River to make up much of the difference.

Surface passage systems such as a spillway weir at McNary Dam boost fish survival by allowing juvenile salmon to safely pass dams at the surface of the river, where they naturally migrate.

The widely recognized, positive relationship between habitat quality and fish survival provides the foundation for this approach. The relationship has been widely described in the scientific literature through studies of previous habitat actions, correlations between habitat improvements and fish survival and continuing research, much of it described later in this report. The tributary habitat component focuses on 18 "priority" populations of salmon and steelhead that required habitat improvements to avoid jeopardizing their survival and recovery, with an emphasis on addressing key factors limiting their growth and survival. A similar but smaller scale program of targeted habitat improvement in the Columbia River estuary complements the tributary effort.

Bringing precision to natural systems

Salmon habitat across the Columbia Basin has suffered more than a century of degradation ranging from toxic mine spoils left in streambeds to irrigation diversions that nearly dry up some streams when salmon arrive to spawn. The extent of the impacts, combined with the need for further mitigation of dam impacts, led the BiOp to call for specific improvements in habitat quality and quantity for protected fish in many different rivers and streams, each with its own individual ecological concerns. The habitat improvements were designed to produce specific increases in fish survival. To help measure those increases, the BiOp required that watershed experts review habitat actions to estimate the degree to which they would address the key factors limiting growth and survival of target populations.

Spring Chinook salmon spawning in northeast Oregon's Lostine River, which once ran dry in places because of irrigation diversions. A leasing agreement has returned water to sections of the river that once ran dry.

The specificity of the required improvements and demonstrated results for fish may well exceed that of any other BiOp on record. The requirements also stretch the capacity of modern science, which must document and measure the habitat improvements as well as expected increases in fish survival with a degree of precision and certainty that has rarely if ever been accomplished before.

Reviews of the scientific literature have found that many habitat improvements, when well-planned and designed, create more favorable conditions for fish and in many cases improve fish abundance and density (Roni et al. 2008; Beechie et al. 2012). But several reviews also concluded that studies frequently may not capture the true benefit of improvements because of inadequate study design or lack of long term monitoring (Roni, 2008; Bayley, 2002). Insignificant results may therefore reflect ineffective research designs rather than ineffective habitat improvements. Only about 10 percent of aquatic habitat improvements include follow-up monitoring (Bayley and Li, 2008) and most studies have not run long enough to clearly detect improvements in fish populations or identify the specific habitat actions responsible (Bayley, 2002).

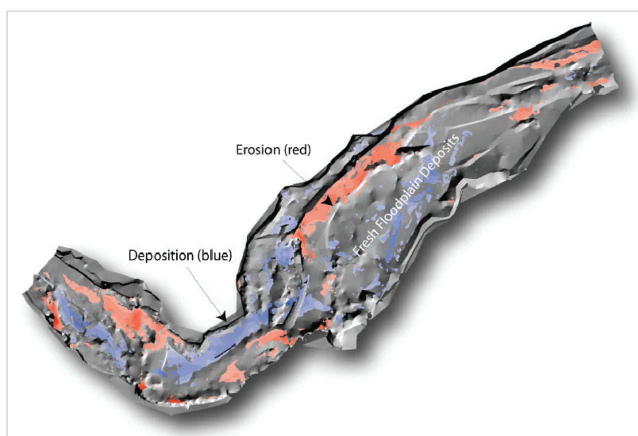
The challenge is compounded by factors including:

- Natural variability: Salmon numbers can fluctuate widely from year to year depending on natural variables such as conditions in the ocean, where salmon spend a great deal of their lives. Such unpredictable factors can drive large shifts in salmon numbers and survival, overwhelming the targeted BiOp improvements and making it difficult to completely isolate one from the other.
- Cost and complexity: The aggressive BiOp timeline requires that many habitat improvement projects proceed without extensive advance study or data collection. Scientists must develop methods to quantify improvements in habitat and fish survival after the fact, with limited pre-project information for comparison.

Pushing the envelope of science

The action agencies under the BiOp have designed an extensive, expensive and sophisticated RM&E program to define the benefits of habitat improvement in ways that have never been done before. The tributary RM&E program costs more than $20 million annually. It is part of an adaptive management approach designed to inform and shape future habitat actions so they deliver increasingly meaningful and cost-effective results for fish and the region.

The current RM&E effort adds to the continuum of scientific research, building on the existing science that demonstrates the benefits of habitat improvement for fish and improving the precision of that information over time. In a 2011 review, the Council's Independent Scientific Review Panel (ISRP) noted the importance of defining



A digital elevation model of the Tucannon River in southeast Washington tracks erosion and deposition down to the centimeter, depicting how habitat actions change the river for fish. Researchers have developed such maps for scores of rivers and streams.

accurate relationships between survival and changes in habitat condition related to restoration. The RM&E program is using cutting-edge techniques to verify and describe such relationships, often at scales rarely attempted before.

This continues a record of innovation in Columbia River research: NOAA Fisheries developed small passive integrated transponder (PIT) tags with BPA funding in the 1980s to track fish along their long migrations. The tags brought salmon life cycles into sharper focus and helped adjust dam operations and other management actions to better protect sensitive stocks. The tags are now used by fisheries scientists around the world and remain an important tool for quantifying habitat benefits in the Columbia River Basin.

RM&E sharpens the picture

The RM&E program demonstrates its value through results that inform and guide the Action Agencies and their partners in developing habitat projects that provide the greatest benefits for fish, in places where they are most needed. The adaptive management element of the BiOp anticipates that research and monitoring will track the results of habitat improvements and identify ways to increase the effectiveness of future actions so the return on investments, in the form of benefits for fish, increases over time.

The science-based approach is designed to avoid pitfalls such as poor project design that can otherwise undermine the success of habitat improvements. Habitat actions can fall short of their objectives if they do not address the root cause of degradation or overlook natural stream processes or if they lack sufficient monitoring (Roni and Beechie, 2013). The RM&E program provides a scientific footing for successful projects.

Since monitoring every one of the hundreds of habitat projects underway would be cost-prohibitive if not impossible, the RME program follows a framework (Columbia Basin Tributary Habitat Improvement: A Framework for Research, Monitoring & Evaluation, 2013) linking several layers of studies and monitoring at different levels and scales, from individual projects to entire watersheds and fish populations. It is designed to answer key management questions that will help guide future action, especially:

- Which limiting factors are most important to address f or fish?
- What habitat improvement actions are most effective at addressing limiting factors?
- How does habitat quality affect fish survival on a large scale?

The most basic monitoring takes place on an individual project scale and is called project action effectiveness, examining how improvements change a specific section of river or stream. It usually yields the quickest results. Larger scale monitoring known as watershed action effectiveness or population action effectiveness analyzes data from broader areas, but takes longer to discern relationships because of the additional variables at play over larger landscapes. Status and trends monitoring tracks the overall condition of habitat and fish populations to help distinguish habitat-driven changes in fish populations from natural variations in their numbers.

This report summarizes evidence for the benefits of habitat improvements, assessing the literature for results that document and describe the relationship between habitat and fish populations. It then highlights more recent results of RM&E in the Columbia Basin, which is increasingly documenting positive results of habitat improvements and concurrent increases in fish populations. Many of the clearest results so far come from project-level action effectiveness monitoring and carefully crafted studies that compare the changes in improved habitat to non-treated areas. Research and status and trends monitoring across larger regions have limited results thus far, but are collecting extensive data and developing new tools and displays to make results more accessible and useful to managers and others who are designing habitat improvement projects.

Looking forward, the appendix to this report includes recommendations that are currently being considered to strengthen continued monitoring and ensure it provides useful results for fish and for the region.

2. Defining the benefits of habitat: Prior studies and reviews

The success of habitat programs under the BiOp rests on how effectively habitat improvement actions create better conditions for fish. This section summarizes the results of relevant landscape-scale analyses of the relationship between habitat quality and fish success and covers reviews of the scientific literature on the success of habitat improvements.

Habitat benefits on a landscape scale

Correlations between habitat quality and fish abundance are important in demonstrating the collective benefits of habitat actions over large scales, such as watersheds or regions including multiple watersheds. Examples would be the upper Columbia River region or lower Snake River. Such analyses provide evidence as to whether multiple habitat improvements together gain enough influence to positively affect entire populations or species. However, effects can be difficult to identify over larger geographic areas because they can be obscured by other variables affecting the same landscapes, such as effects from adjacent land use, fluctuations in annual weather patterns and natural events such as floods, wildfires or landslides.

This section reviews the results of analyses using landscape-scale correlation and regression techniques to detect the influence of habitat improvement actions on fish survival in key parts of the Columbia Basin. While correlations are not conclusive proof of cause and effect, they provide useful information on associations and linkages. What the results demonstrate thus far is that protected lands, high-quality stream habitat and habitat improvement actions such as those proceeding under the BiOp are associated with significantly higher juvenile fish survival. These analyses, which probe data for statistical relationships, complement project-level research and monitoring designed to detect the effects of habitat actions on fish numbers.

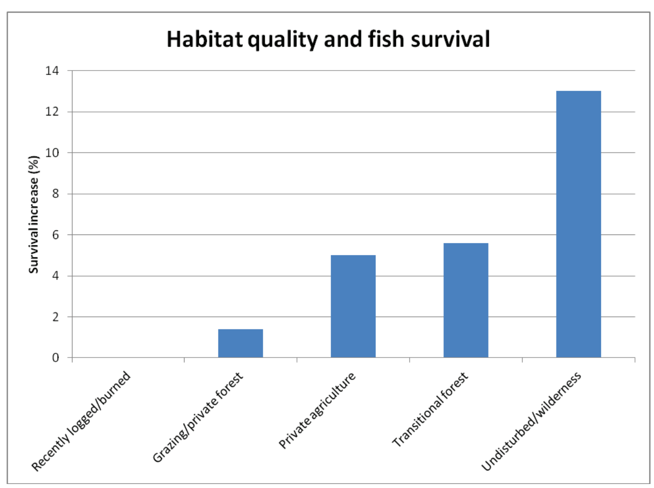
Finally, this section concludes with a review of other research that has identified a range of benefits for fish of habitat improvement actions.

Fish-habitat relationships in the Snake River Basin

One of the first studies to connect habitat quality to anadromous fish survival on a large scale emerged from the Snake River Basin. The research by Paulsen and Fisher (2001) found higher survival among fish from relatively undisturbed habitat affected by fewer roads. The results indicate that roads and intensive land use or development can depress survival of juvenile fish. They also provide evidence that the protection of relatively undisturbed habitat can benefit fish as well as mitigate the detrimental effects of development on habitat.

> **FINDING:**
> Wild juvenile Snake River salmon from undeveloped habitat survive at a 13 percent higher rate compared to salmon from more disturbed habitat, indicating a relationship between habitat quality and fish survival.

Few other studies had previously examined the relationship between juvenile salmon survival and habitat quality, which the authors attributed to the time and expense involved



Differences in parr-to-smolt survival of juvenile wild Snake River spring-summer Chinook attributed to varying types of land use and protection, as reported by Paulsen and Fisher (2001).

and complicating factors such as climate that can obscure the relationship. Their research built on earlier unpublished findings by the National Marine Fisheries Service linking the detection of PIT tagged juvenile Chinook salmon at Snake River dams to the habitat quality of their home streams. That earlier work suggested that fish from higher quality habitat were more likely to survive long enough to reach the dams on their way to the ocean.

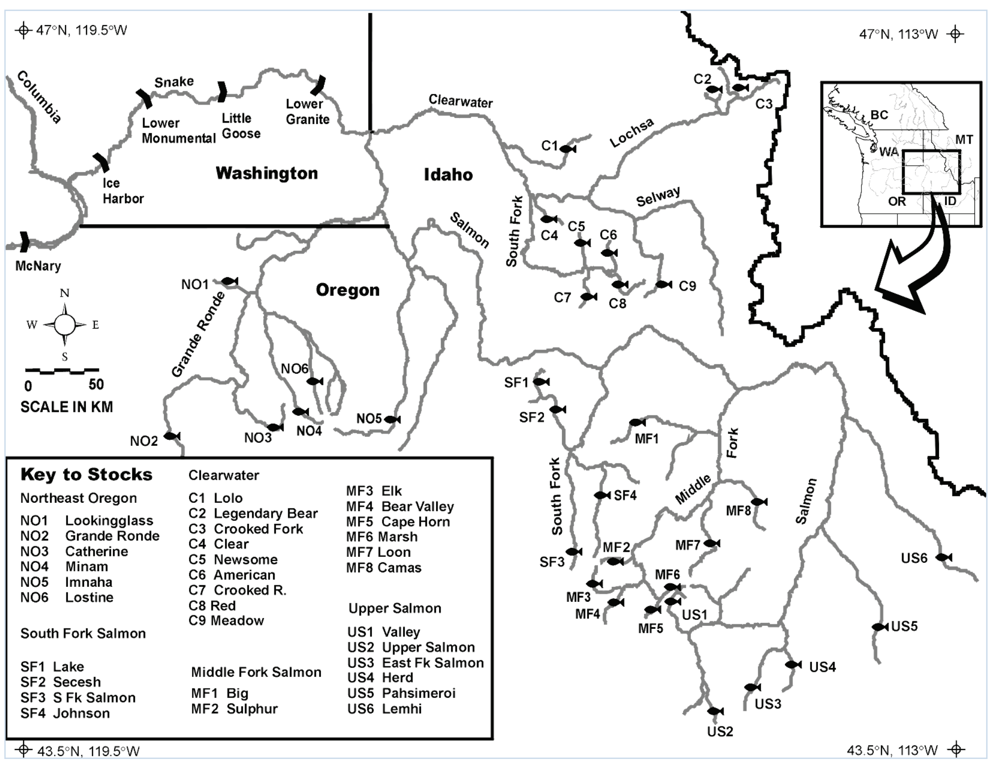
Paulsen and Fisher similarly used the detection of PIT-tagged wild Snake River spring-summer Chinook migrating downstream past Snake River dams to estimate their survival. They then compared the survival of fish from 20 different watersheds, each with different land-use characteristics. The watersheds varied in size but included creeks or smaller rivers and reaches of rivers such as the Grande Ronde or Lostine rivers in Oregon and the Lemhi River in Idaho. Comparing fish from different watersheds revealed relationships between the parr-to-smolt survival of wild Snake River spring-summer Chinook and two indices of land use: mean road density and land use classifications such as agricultural use or wilderness.

The study determined that fish from areas of reduced human development such as areas of relatively low road density or disturbance survived at a higher rate than those from areas of more intensive la nd use including higher road density and agricultural development. The difference could be substantial: Fish reared in less disturbed wilderness (a land-use category, but not necessarily congressionally designated wilderness) demonstrated 13 percent greater survival than those reared in recently logged or burned forest habitat. All fish examined survived to reach the dams at a rate of 22 percent, so the 13 percent increase associated with less disturbed habitat reflects a substantial a significant addition. The results support the BiOp strategy of protecting and improving higher-quality habitat to retain the integrity of natural processes and systems.

The authors noted that their study was the first of its type they were aware of and took advantage of fish tagged for other reasons. Ideally, they said, their analysis could be extended to other fish populations and areas to broaden the results.

Habitat improvements relate to higher fish survival

As biological opinions for the Federal Columbia River Power System increasingly looked to habitat improvements to promote fish survival, the same researchers analyzed the fish survival data for evidence of whether such improvements could explain higher survival. Few previous studies had examined such relationships: They noted that surveys of more than 2,000 published references found empirical studies "very rare" and they could find none involving inland salmon stocks such as spring-summer

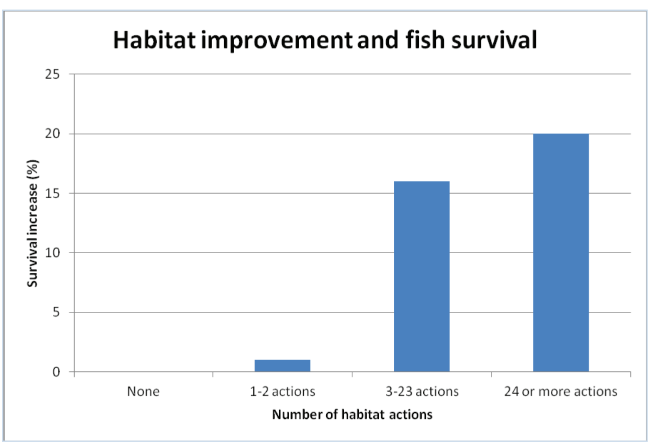


Paulsen and Fisher examined 11 years worth of data from juvenile salmon tagged at 33 sites throughout the Snake River Basin for relationships between fish survival and habitat improvement.

(stream-type) Chinook salmon. The results provided a new benchmark for the biological benefits of habitat actions, finding that habitat improvements accounted for as much as about 20 percent higher survival for fish from areas with the most actions (Paulsen and Fisher, 2005).

> FINDING:
> Concentrated habitat improvements have been associated with up to a 20 percent increase in juvenile salmon survival, relative to fish from areas with few improvements.

The evidence emerged from analysis of PIT tag data from 33 wild juvenile fish tagging sites in the Snake River Basin, each with at least 100 fish tagged in each of at least five of the 11 years from 1992 to 2002. More than 400,000 parr had been tagged at all the sites during that period. The study compared the proportion of fish from each site that survived to reach Lower Granite Dam, the first dam they would pass on their migration to the ocean. The study also drew on records of habitat improvements from federal and state agencies and local watershed groups, narrowed to those actions the researchers considered most likely to affect juvenile salmon survival. The actions included riparian restoration or controls on grazing, in-stream habitat improvements and improved passage within one kilometer of the main spawning or rearing locations of the tagged fish.



Juvenile wild Snake River spring-summer Chinook from areas with 24 or more habitat improvement actions demonstrated about 20 percent higher survival than those from areas with no improvements, based on 2005 study by Paulsen and Fisher.

The analysis showed significantly higher survival of juvenile fish from areas with large numbers of habitat actions compared to those from areas with fewer actions. The results were consistent across various models used to assess fish survival: Nearly all models that considered habitat important showed a positive correlation between habitat improvements and juvenile survival. Overall, about 20 percent of all tagged juvenile fish survived to reach Lower Granite Dam. However, about 20 percent more fish survived from areas with large numbers of habitat improvement actions compared to fish from those areas with few or no habitat actions. That suggested that habitat improvements could account for a potential doubling of overall juvenile survival. The potential increase was nearly twice the survival improvement anticipated in the 2000 Biological Opinion from improvements at hydroelectric dams. While the authors cautioned that more study was necessary, they concluded that if the relationship between habitat and fish survival was indeed causal, that "substantial increases in juvenile survival rates may be feasible for many of the stocks considered in this analysis."

They noted some caveats, such as logistical and legal limits that may constrain habitat improvements in congressional designated wilderness areas. They also noted some signs that habitat actions may not yield as much benefit in areas such as the Lemhi River with many previous habitat actions. That could be because problems have been remedied and the Lemhi is approaching a point of diminishing returns, or because significant additional work is still needed to overcome past degradation.

Projecting the potential of habitat actions through modeling

Other analyses modeled the potential for habitat improvements to benefit Snake River salmon populations (McHugh and Budy 2002; Budy and Schaller 2007). Budy and Schaller (2007) found potential for an average 104 percent potential increase in total life cycle survival from tributary habitat improvements, but concluded that was not enough, in the absence of survival increases in other parts of the life cycle, to ensure the viability of most populations. They noted that the analysis considered only physical factors associated with stream degradation that influences temperature and substrate, excluding factors such as irrigation diversions and exotic species. Still, the finding underscores the purpose of the all-H, life-cycle approach

to salmon protection that includes major improvements and performance standards at dams. The authors noted that all populations are at risk of habitat degradation and that habitat condition has likely kept some populations from going extinct. They suggested that similar modeling could help focus habitat actions on populations where they will make the most difference.

Another analysis by Roni et al. (2010) used results from evaluations of habitat actions in western Washington and Oregon to predict how different concentrations of restoration actions would affect juvenile coho salmon and steelhead in the Puget Sound basin. The results generally agreed with other estimates of how habitat improvements increased fish numbers. Simulations by Roni et al. showed that habitat restoration across a watershed could considerably increase juvenile fish numbers, which is generally consistent with the findings of Paulsen and Fisher (2005). Roni et al. concluded that about 20 percent of floodplain and in-channel habitat would have to be restored to produce a 25 percent increase in juvenile fish, the minimum increase considered detectable under most monitoring programs, and that additional habitat improvements would provide greater certainty of a detectable increase in fish numbers.

In 2011 Paulsen and Fisher updated their 2005 analysis with new data on survival and habitat improvement projects through 2009. They found that the same relationships still held true. The substantial additional survival data and number of habitat improvement projects examined increased the confidence of the conclusions (Charlie Paulsen, personal communication, 2012).

Tracing the benefits of habitat improvement to adult fish

What ultimately matters to fish populations is how many fish return as adults to spawn. In 2011, Paulsen and Fisher expanded their analysis to detect relationships between habitat improvements and the number of juvenile fish that survive to return as adults. They found that the influence of habitat improvements carried through to adulthood, with fish from areas with the most habitat projects surviving their downstream migration and years at sea and returning as adults at a higher rate than those from areas with fewer projects (Paulsen and Fisher, unpublished manuscript, 2011).

The analysis examined data from 700,000 wild Snake River Chinook parr and 90,000 smolts with PIT tags and noted that the results were significant enough to be important to fisheries managers. The study found that fish from areas with 47 or more habitat improvement actions survived to return as adults at an approximately 50 percent higher rate on average than fish from areas with five or fewer actions. The statistically significant results indicate that large numbers of habitat improvements such as those underway through the BiOp may benefit salmon not only in their early life as juveniles, but also through their return to spawning streams as adults. Compared to the earlier 20 percent difference in juvenile survival detected in the 2005 study, the additional increase noted through adulthood suggests that the benefits of habitat improvements carry through the salmon life-cycle.

> **FINDING:**
> The benefits of habitat improvements carry through the salmon life cycle to adulthood, accounting for about 50 percent higher survival than fish from areas with few improvements.

Other correlations appeared to explain the relationship between habitat actions and increased survival. Relatively higher numbers of habitat actions were associated with larger juvenile fish, suggesting that fish rearing in streams with more habitat improvements grow faster and begin their migration downstream earlier. Larger fish that begin the trip to the ocean sooner were, in turn, more likely to survive their trip down the river and their years in the ocean to return as adults.

The authors suggested that more limited studies that focus only on short-term, site specific effects of habitat actions on juvenile fish may overlook the long-term benefits of the actions. They said the results provided a foundation for more detailed studies in Intensively Monitored Watersheds (IMWs) designed to identify the mechanics of relationships between fish survival and habitat actions. IMWs and other focused research are now underway through the BiOp's research and monitoring program.

Extending the connection through additional habitat data

Further work by Paulsen and Fisher (personal communication, 2012) sought to extend the analysis to

other habitat measures, specifically a wealth of habitat data collected by the U.S. Forest Service's Pacfish/Infish Biological Opinion (PIBO) monitoring program since 2001. The program measures habitat attributes such as stream temperatures and other characteristics at hundreds of sites on federal lands throughout the West to evaluate and track habitat conditions in the range of steelhead and bull trout, including the Columbia Basin. Since PIBO represents one of the largest available catalogs of habitat conditions, Paulsen and Fisher examined whether the PIBO data – and by extension variations in the conditions it tracks, including temperatures and in-stream structures – could help explain differences in juvenile fish survival.

The PIBO analysis identified relationships indicating that the habitat data could account for approximately 17 percent of the variation in juvenile Chinook survival as well as about 23 percent of the variation in fish length, an indicator of growth. In short, variations in fish survival and length tracked variations in habitat conditions. The findings further underscore the connection between habitat and fish survival, which underlies the BiOp's focus on habitat improvements.

The results also indicate that PIBO habitat measures track habitat qualities important to fish and could provide a useful barometer of fish habitat conditions and related survival. This is important because BPA is working with other federal agencies to use PIBO data to buttress the Columbia Habitat Monitoring Program (CHaMP), which tracks fish habitat trends as a measure of progress under the BiOp. PIBO results indicate generally improving habitat conditions for fish on federal lands, which represent approximately half of the roughly 150 million acres in the Columbia Basin.

FINDING:
A review of several studies in western streams found a 123 percent average increase in juvenile salmonid density in rehabilitated habitat.

Surveying multiple studies of habitat improvements

While few studies have examined fish-habitat relationships on a large scale, some research has reviewed numerous studies of individual habitat improvements spread across large geographic areas. Such reviews go beyond effectiveness monitoring of individual actions to look for consistent effects or results that would further demonstrate that habitat actions can produce predictable benefits for fish.

One of the earlier reviews, from 1996, examined the results of habitat improvements in western states from Alaska to California from the 1970s through the 1990s. The authors pursued any studies that examined the effects of habitat enhancement on anadromous fish abundance and sought out additional unpublished data, considering only studies that included paired reference or control sites to compare to the rehabilitated reach. Following statistical analysis, the review concluded that stream restoration supports significant increases in the densities of juvenile salmon and steelhead and that reopened or restored off-channel habitat could significantly increase the number of juvenile fish migrating to the ocean (Keeley et al. 1996).

The review of eight studies of habitat improvements in 14 different streams found an average increase in juvenile salmonid density of 123 percent, although with considerable variation at different sites and among species. The studies measured the response of steelhead as well as Chinook and coho salmon. Although the results for Chinook were not statistically significant, the authors attributed that to a dearth of data rather than lack of benefits. They noted that post-rehabilitation fish densities were always greater than those prior to habitat projects in the studies assessed. Although the studied projects included coastal streams not directly comparable to interior habitat, the results demonstrate that well-planned habitat improvements can significantly benefit fish.

The review also concluded that benefits for juvenile fish appeared large because juvenile fish responded strongly to habitat improvements. It also found that expanded access to side channels and ponds was highly productive for salmon, with the most data available for chum and coho salmon. The review calculated that additional side channels could produce as much as 1.58 additional adult chum per square meter. Side channel access and enhancement is a key habitat improvement strategy in the BiOp.

A later statistical analysis, or meta-analysis, by Whiteway (2010) of data from 211 stream rehabilitation projects found a significant improvement in habitat attributes – pool area, average depth, large woody material, percent cover and riffle area – following in-stream habitat

improvements. The analysis also found a statistically significant 167 percent average increase in salmonid density following the improvements, although there were large differences between species. The analysis examined the effectiveness of five types of in-stream improvements including weirs, deflectors, cover structure, boulders and large woody material. The authors noted that their results generally agreed with earlier studies and that unsuccessful projects they identified may have suffered from ineffective study design or unexpected events such as floods that confounded results.

Other reviews of habitat improvement results

Other reviews of published studies have examined the relative strength of the scientific literature in establishing the biological benefits of different types of habitat improvement projects and their effectiveness in addressing environmental factors such as climate change. The reviews generally did not report specific numerical estimates of biological benefits of restoration. A review of 345 papers on the effectiveness of stream rehabilitation around the world found strong evidence that reconnection of isolated habitats, rehabilitation of floodplains and placement of

Response time and longevity of restoration techniques

For processes restored: C= connectivity, S=sediment, H=hydrology, R=riparian. For habitats: F=floodplain, R=riffle, P=pool, S=spawning and C=cover. For response time, darker shading is faster and for longevity, darker shading is longer-lasting. Adapted from Roni and Beechie, 2013.

Technique	Processes restored	Habitat restored	Response time in years	Longevity in years
Culvert replacement	C, S, R		1-5	>50
Fish passage	C		1-5	>50
Levee removal or setback	C, S, R	F	5-20	>50
Floodplain reconnection	C, S, H	F	1-5	>50
Road removal	C, S, H		5-20	>50
Road resurfacing	S		5-20	10-50
Stabilization	S, H		5-20	>50
Instream flows	H		1-5	>50
Alter agricultural practices	S		1-5	10-50
Restore sediment sources	S	R, S	1-5	>50
Riparian replanting	S, R		>50	>50
Remove invasive plants	R		1-5	<10
Fencing	S, R		1-5	>50
Add logs or boulders		R, P, S, C	1-5	10-50
Engineered logjams		F, P, C	1-5	>50
Gravel addition		F, R, P, S, C	1-5	10-50
Remeandering channel	C	F, R, P, S, C	1-5	>50
Dam/barrier removal	C, S, H, R	F, S	1-5	>50
Create floodplain habitat		F, S	1-5	>50
Beaver reintroduction	C	F, P	1-5	10-50
Nutrient addition			1-5	<10
Bank stabilization	S, R	C	1-5	10-50

in-stream structures proved effective in improving habitat and increasing local fish abundance in many circumstances (Roni et al. 2008). Other actions such as riparian rehabilitation, sediment reduction and dam removal have produced positive results but may take years or decades to demonstrate clear benefits for fish, at least in part because little long-term monitoring has been undertaken.

The authors of the review stressed the need for more complete assessment of watershed processes and factors that limit fish populations and the need for longer-term and larger-scale monitoring. Such assessments and monitoring are underway as part of the BiOp approach to habitat improvement.

Another review of the literature examined the potential of various rehabilitation actions to ameliorate the effects of climate change, such as increases or decreases in stream flows and temperature shifts that could affect aquatic systems and associated fish populations (Beechie et al. 2012). The review considered the potential of habitat actions to improve the resilience of river systems and salmon populations by protecting or restoring habitat diversity necessary to support varied life history strategies within species. Actions that improve conditions for a wider variety of life histories are more likely to conserve adaptations and strategies that allow fish to endure changes in climate.

Based on the literature, the authors concluded that restoring floodplain connectivity and natural flow patterns and rehabilitating incised stream channels are most likely to ameliorate flow and temperature changes, while also increasing habitat diversity and resilience of species. In contrast, in-stream rehabilitation may not provide enough lasting benefits to effectively address climate change. The authors suggested that the anticipated benefits of habitat improvement actions in vulnerable locations should be evaluated relative to the projected effects of climate change.

Assessing two decades of habitat improvement for salmonids

A recently published long-term review of habitat improvements in the Blackfoot River Basin in Montana (Pierce 2013) provides useful perspective in terms of the time required to document a response by fish populations and how well benefits are sustained over time. Although the improvements targeted wild trout populations, the results likely translate to other salmonids with similar habitat preferences. The study examined a collaborative stream restoration program that began in 1990 to improve degraded wild trout habitat, mainly on private land. The program included a wide range of reach-scale habitat actions similar to those employed in the Columbia Basin, including channel reconstruction and in-stream habitat structures, flow improvements, installation of fish ladders and screens at irrigation diversions and modification of grazing practices.

The study examined trends in trout abundance of at least five years on 18 tributaries that were the sites of habitat actions from 1990 to 2005. Average trout abundance started out significantly lower in sites targeted for improvement than comparable reference sites, reflecting the degraded nature of the targeted habitat. Within three years following the habitat actions, trout abundance increased to the point that it was no longer significantly different from the comparison sites. The increases were sustained over the long term (5-21 years) in 15 streams but declined again on three streams, apparently because of the return of grazing and irrigation impacts. Trout responded most strongly in the upper stretches of the basin, with the return of more natural stream conditions shifting the local salmonid mix toward native trout species. Long term monitoring identified a need for adaptive management on most projects, including follow-up actions in stream channels, and fostered improved communications among landowners and other stakeholders. The authors concluded that adaptive management "thus proved vital to the overall sustainability of wild trout fisheries throughout the basin."

A similar but more limited review by White et al. (2011) of in-stream improvements in Colorado mountain streams found that adult trout abundance increased rapidly after log structures were installed in 1988. Adult abundance remained 53 percent higher on average in the treatment streams than comparison untreated streams 21 years later. The authors concluded that properly designed in-stream improvements can produce long-lasting benefits for fish.

A research team installs an underwater antenna in Idaho's Lemhi River to detect PIT tags in juvenile fish passing over it. The Lemhi is an Intensively Monitored Watershed, where detailed monitoring is examining the response of fish to the reconnection of cool-water tributaries.

3. The next step: Unraveling the fish-habitat mechanics

Although large-scale studies and reviews have provided evidence for the lasting benefits of habitat improvement, they have consistently called for more detailed and long-term research to discern the mechanics of the fish-habitat relationship and, in turn, better inform and guide the planning and execution of habitat improvements. The RM&E program under the BiOp is likely one of the most comprehensive programs of such research ever undertaken.

While all habitat projects are subject to implementation monitoring, more detailed research and experiments are underway through the BiOp's Integrated Status and Effectiveness Monitoring Program (ISEMP), which is related to a series of Intensively Monitored Watersheds, or IMWs. ISEMP focus areas including IMWs undergo detailed monitoring and tracking of adult and juvenile fish through methods and tools ranging from remote sensing to underwater antennas that track fish through stretches of river. IMWs may test specific hypotheses through before-after-control-impact (BACI) experiments, which monitor stream reaches before and after habitat improvement projects and compare the results between reaches with improvements and others without improvements. The comparisons can more clearly gauge the benefits of habitat improvements. Researchers then examine and analyze the data for evidence of the most important habitat variables, the details of how improvement actions can reshape those variables and, finally, how future actions might be expected to influence fish populations.

Additional data is supplied by the Columbia Habitat Monitoring Program (CHaMP), which monitors habitat conditions at hundreds of sites across the Columbia Basin. The combination of CHaMP habitat data and fish monitoring results from ISEMP have begun to detect important relationships between habitat treatments and effects on fish.

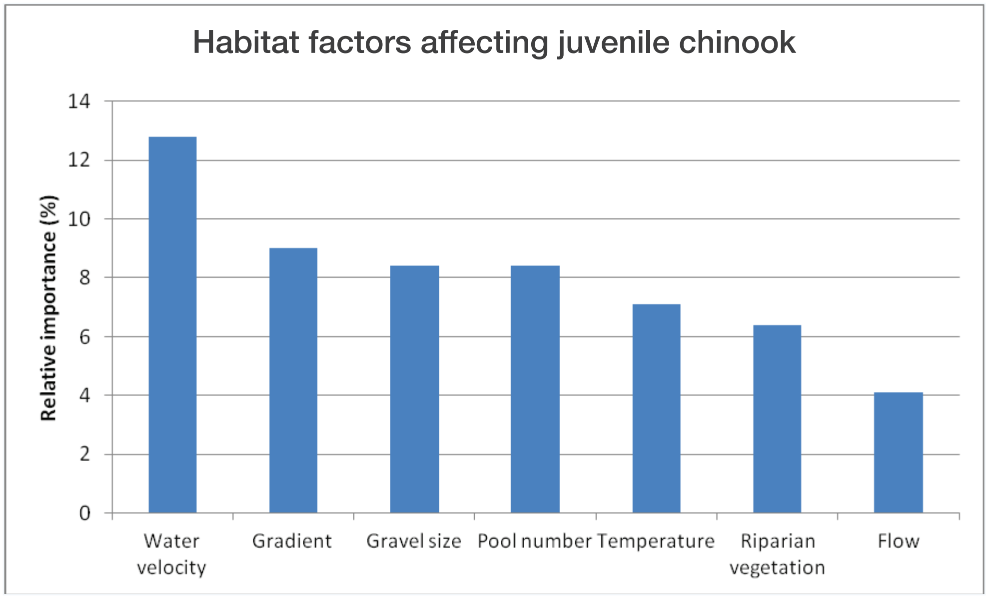
Since research and monitoring of specific projects or limited reaches operate under more controlled conditions with fewer variables at play, they can more clearly expose the relationships between actions and results. The monitoring can take different forms, from basic implementation monitoring that determines whether actions have been completed properly and are functioning as anticipated to planned experiments that compare the results of specific habitat actions to control areas that are left alone.

The following examples provide snapshots of the emerging results of the BiOp research program, which is confirming the benefits of habitat improvements while also revealing:

- Habitat qualities that most influence fish density and the degree of improvement expected to produce the greatest benefits for fish.
- The effectiveness of habitat actions in addressing key factors limiting fish populations and the response of fish to those actions.
- How the fish response to habitat actions can help predict the outcome of future actions, helping managers weigh the most cost-effective investments.

FINDING:
Juvenile fish density is closely correlated with certain habitat factors, which can help predict fish density across the landscape.

Example: Identifying habitat factors that influence fish density



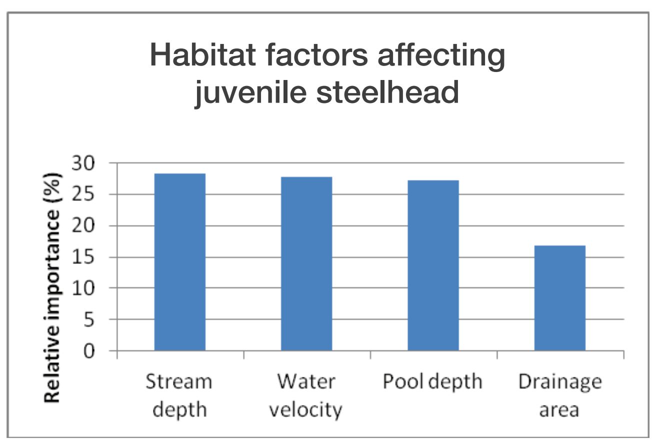
Relative importance of the most influential habitat factors affecting the density of juvenile Chinook, based on data collected by ISEMP in the Wenatchee subbasin (ISEMP 2012).

In 2004 scientists began examining the relationship between fish densities and certain habitat attributes in the Wenatchee River subbasin. The study compared fish density in different reaches against a series of habitat factors such as the amount of fast water and number of pools to determine which factors were most closely associated with juvenile Chinook salmon and steelhead density. Although the association by itself does not prove that those specific factors individually control fish numbers, additional years of data add confidence to the relationship and the expectation that improvements in those habitat factors associated with higher fish densities can help increase fish populations.

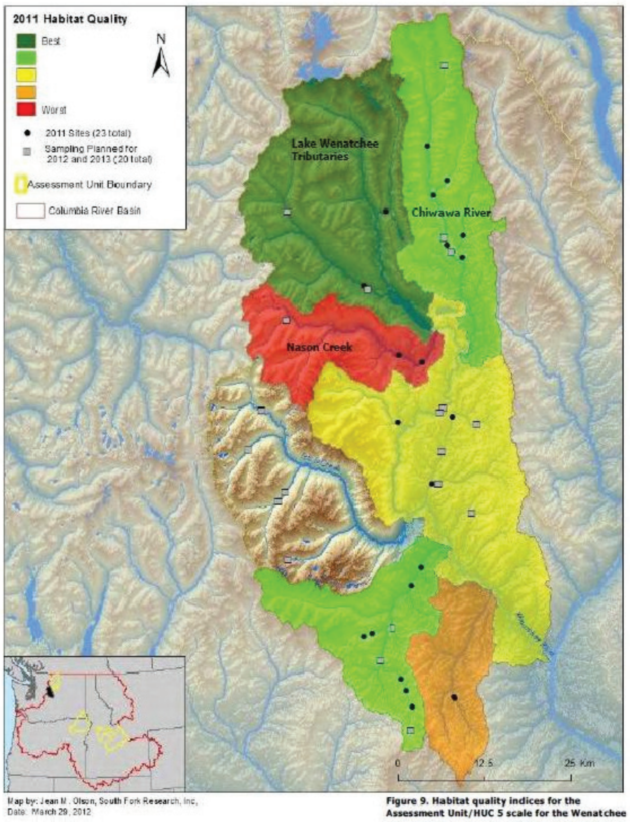
Analysis of the relationships through 2010 produced a ranking, in order of importance, of habitat metrics that most affect the density of juvenile salmon and steelhead. The ranking further confirms the relationship between habitat conditions and the number of fish in key areas. It also can begin to guide habitat improvement actions so that they address the habitat conditions most likely to produce more fish. While previous studies have documented such habitat factors, research under ISEMP and CHAMP is detailing the relationships on a broader scale than ever and in lesser known watersheds.

Researchers further tested the Wenatchee results by comparing fish densities in areas with similar habitat characteristics in various parts of the Wenatchee subbasin and found that they generally produced the same results. The tests add confidence to the relationship between habitat quality and fish numbers, helping biologists map habitats that support fish and identify the areas where habitat actions could most improve conditions.

Besides indicating which habitat factors are most important to fish, the analysis further detailed the nature of the connection. It revealed that the relationship between fish density and habitat attributes is not linear; that is, at certain thresholds, habitat qualities such as water velocity may become “just right” to produce proportionally larger



Relative importance of habitat factors influencing the density of juvenile steelhead, based on ISEMP data from the Wenatchee subbasin (ISEMP 2012).



Preliminary habitat quality map of the Wenatchee, classifying habitat quality based on initial indication of habitat factors most closely linked with higher juvenile habitat density (ISEMP, 2012).

increases in fish density. For example, juvenile Chinook densities tend to be higher in areas protected from fast water but decline and eventually bottom out as fast water increases. This indicates that sites with less than 5 percent fast water are important to juvenile Chinook and that reaches typified by high water velocity might benefit from creation of slower water refugia with a demonstrated relationship to higher fish densities.

Similar findings have emerged before (Smith and Brannon 2006), but the detail of the recent results can further inform the type and location of habitat improvements.

Fish density also has a relationship with the proportion of gravel on the stream bottom, highlighting another important relationship between habitat and fish numbers. Chinook density rises when the proportion of coarse gravel exceeds about 30 percent, indicating that lesser amounts of gravel may be limiting fish juvenile Chinook densities

Seeing streams as fish do

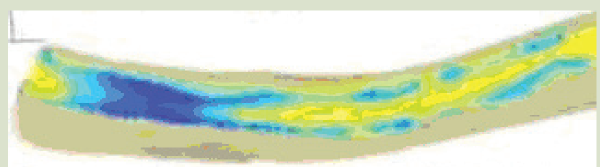
What if biologists planning habitat improvement projects could see a stream as fish do, instantly spotting prime places to hunker down and hide or lie in wait for food?

A new method may help them do that and could turn out to be one of the best available tools for gauging the value of habitat for fish.

It's called the Net Rate Energy Intake index and, in short, it maps streams based on how hard fish have to work to eat and grow – in other words, how tough it is for them to make a living in one part of a stream versus another. The maps can help biologists focus habitat improvement projects – say, installation of log structures for hiding – where the actions will best help tilt the balance in favor of the fish.

Scientists are testing the NREI index as a tool for evaluating habitat and guiding rehabilitation actions under the FCRPS BiOp, which calls on habitat improvements in the Columbia Basin to mitigate the impacts of federal dams. The index uses the topography of streambeds to assess the way water moves through them and how much energy fish expend to pursue and capture drifting food items or prey.

Blue indicates higher carrying capacity in an NREI map of a stream reach.



Areas where fish gain more energy from food than they burn to get it have a positive NREI index. The greater the index, the faster fish grow. The results can help biologists estimate the carrying capacity of stream reaches and, better yet, identify places where habitat improvements could boost the carrying capacity and growth of fish.

Very preliminary tests in the John Day and Asotin rivers found that the NREI index predicted the number of fish using reaches of the two rivers extremely well, underscoring how closely fish numbers follow habitat conditions. If it holds up during continued testing, the NREI could help scientists use topographic information and other habitat data collected by CHaMP surveys to estimate fish abundance and growth in other stream reaches.

It could also provide a powerful means of positioning habitat improvements where they could most increase fish numbers.

and could be targeted by habitat improvement actions. The results further characterize the nature of relationships between fish and habitat conditions, which can better inform habitat improvement actions. They should not be interpreted to suggest that any one habitat factor is the secret ingredient for fish success but that the many habitat qualities fish need may have optimal levels most closely linked with fish growth and survival.

While more work will further define the thresholds and test the results against data beyond the Wenatchee subbasin, the results can help identify the limiting factors most important to address and the actions that would best address them. Understanding threshold relationships can also help determine where restoration can be most effective and how much restoration is likely to be cost-effective. For instance, the Wenatchee data indicate that once coarse gravel proportions exceed 30 percent in such a system, Chinook densities level off. That suggests that further resources could be focused on other critical limiting habitat factors.

Scientists tested the Wenatchee results by comparing fish densities in different parts of the subbasin against the documented fish-habitat relationships. They found that the relationships predicted the actual densities fairly well, adding further credence to the connection between the two. The predictions based on the combined set of habitat factors matched the actual densities even more closely.

The next step was to examine the relationships on a larger scale. Researchers combined habitat data from 152 CHaMP monitoring sites that were also sampled for fish under ISEMP in the Lemhi, Upper Grand Ronde, John Day, South Fork of the Salmon, Entiat and Wenatchee subbasins. The results are not directly comparable to those from the Wenatchee alone because the measured habitat metrics are slightly different, but they again demonstrated that certain habitat metrics have large influences on fish density and are likely promising targets for habitat improvement actions. The results matched known relationships between habitat and fish densities, such as that higher Chinook densities are found in areas with more pools and better water quality. While that in itself may not be surprising, it validates the relationship between habitat quality and fish and verifies that the relationships can help managers determine what type of restoration actions in which areas are most likely to improve fish densities.

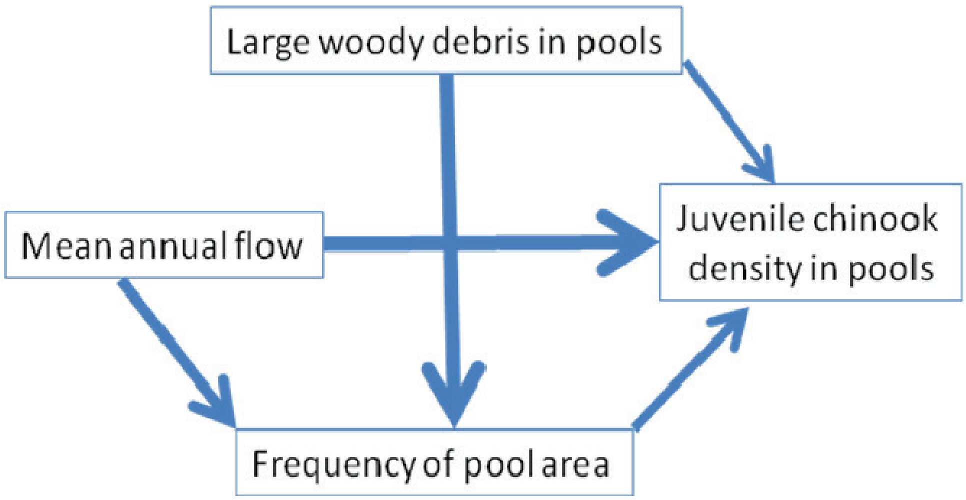
Researchers demonstrated the potential value of the findings to managers by using the data and results to map high quality habitat likely to support higher fish densities and lower quality habitat that could be improved through habitat actions. The habitat maps of the Wenatchee based on the fish-habitat relationships generally matched existing thinking about various levels of habitat quality in the subbasin, adding further strength to long-held assumptions that habitat quality influences fish numbers. It also indicates that with further research and analysis, the findings could be applied to other, lesser-known watersheds to distinguish high-quality reaches that could be protected as well as lower-quality reaches that could benefit from improvements.

FINDING:
Large wood in streams positively affects juvenile chinook salmon density directly, but also indirectly by playing a role in pool formation, which also benefits salmon. But location matters, because other influences can overwhelm the benefits in some types of streams.

Example: Detailing the dynamics of the fish-habitat relationship

On the Upper Grande Ronde River, biologists with the Columbia Intertribal Fish Commission used a technique called structural equation modeling to unravel the relationships between key habitat conditions and fish density (McCullough et al. 2011). They found that habitat characteristics such as the volume of large woody material in streams positively influenced fish density as well as the frequency of pools, which in turn also positively affected fish density. Teasing out such interactive effects not only confirms the connection between fish and habitat, but also reveals the mechanics of the relationship so managers can more accurately predict and calculate the benefits of habitat improvements.

Structural equation modeling tests and quantifies assumed relationships and can delve deeper into the interactions between and among habitat factors (Grace 2006). This



Relationships between habitat factors and fish density, as validated by structural equation modeling. An arrow indicates a positive influence, with wide lines representing primary and thin lines representing secondary interactions. All identified effects represented by arrows are statistically significant. Source: Mccullough et. al. (2011)

is important because the combined effects of various habitat factors may affect fish differently than the same factors in isolation. CRITFC biologists combined CHaMP data on habitat conditions with fish density data obtained by snorkel surveys. They then used structural equation modeling to test their assumptions about how habitat conditions affect each other and quantify the influence on fish density.

They confirmed assumptions that the volume of large woody material and the frequency of pools both positively affected fish density, validating the basic relationship. However the analysis established a more complex chain of effects: large woody debris also significantly influences the frequency of pools, further affecting fish density. Further, mean annual stream flow affects both the frequency of pools and fish density. The relationships can be visually illustrated through a diagram depicting the primary and secondary effects of each of these attributes. This indicates that the effects of stream flow could in some cases outweigh the influence of pool frequency or woody debris volume, which should be considered in planning for habitat actions.

The analysis will gain statistical strength with the additional data collected in future years. Quantifying the relationships and effects of habitat actions can determine the extent of improvements necessary to produce the outcomes designated in the BiOp.

The CRITFC analysis in the Grande Ronde also found that the relationships differ depending on the stream reach. In mountain headwater streams, for example, the pool area and volume of woody debris did not influence fish density as expected, indicating that other factors were dominant in terms of the fish response (Montgomery and Buffington 1997). However, in lower floodplain reaches, pool area and woody debris positively affect fish density at statistically significant levels, confirming the relationship and the beneficial effects of habitat improvement actions involving those factors.

Example: Fish survival and abundance follow habitat improvements

An intensively monitored watershed in Bridge Creek, a tributary of Oregon's John Day River, provides a revealing example of the benefits of experimental restoration with control areas for comparison. The results illustrate how quickly effective restoration actions, in this case carried out in part by beavers, can bring about changes in habitat and concurrent improvements in fish populations (Bouwes et al. 2012).

Bridge Creek has suffered from erosion and channel incision, a degraded condition that can be exacerbated by intensive grazing, development and other factors. Incised streams cut deeply into the ground and become faster, straighter and disconnected from the floodplain and riparian vegetation. The result is higher water temperatures and loss of spawning and rearing habitat. Studies have linked channel incision to degraded water quality, limited

A beaver dam washed out by unnaturally strong flows in Bridge Creek prior to experimental steps to stabilize the structures.

habitat capacity and reduced fish populations (Shields et al. 2009).

The experimental restoration involved installing posts in certain stretches of Bridge Creek to help anchor beaver dams that had regularly washed out during periods of high flow. Stable beaver dams were expected to slow the water flow, restoring more natural stream dynamics including sinuosity, reconnection to the floodplain, reduced water temperatures and improved groundwater exchange benefiting riparian vegetation. That in turn would benefit fish by providing more food and refuge and more favorable conditions.

FINDING:

Finding: Targeted habitat actions in a tributary of the John Day River improved habitat conditions that had been limiting fish numbers, yielding increases in juvenile fish abundance and survival.

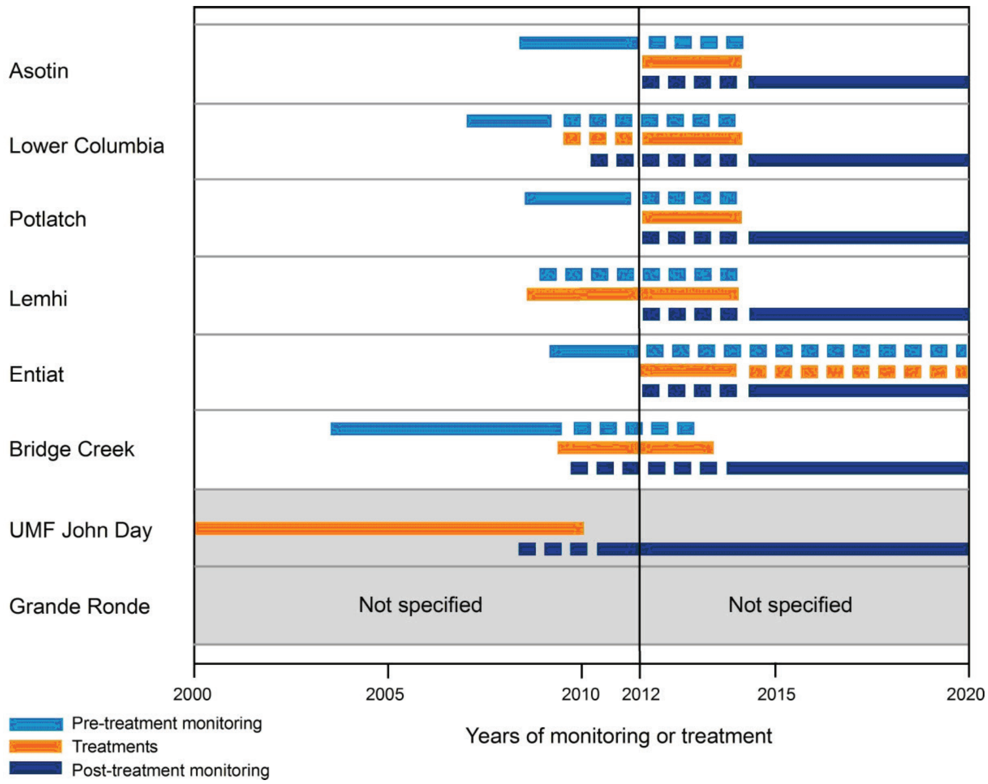
The anchors successfully stabilized a large proportion of beaver dams, leading to positive results for fish. Aerial imagery (see page 3) and digital elevation models documented relatively quick changes in the stream channel and riparian vegetation considered favorable for fish. Deposition increased in the experimental reaches as the incised streambed began to recover and the stream began to regain access to its floodplain. The depth, frequency and percentage of pools increased compared to the control area, indicating that the creek was slowing down and evolving into more complex and favorable habitat for fish.

Fish populations also showed changes, with steelhead abundance in the experimental reaches steadily rising beyond that of the control areas in the years following the treatment. Fish survival also improved: Steelhead survival had been higher in the control area preceding the treatment to stabilize beaver structures but afterwards survival in the area of the experiment rose to exceed that of the control area. The area and timing of the response in fish populations suggests that the improvements in survival and abundance were the result of habitat improvements (Nick Bouwes, personal communication, 2012).

4. IMWs: Assessing benefits at the population scale

An intermediate level of research and monitoring focuses on quantifying changes in the productivity or capacity of fish populations associated with habitat actions to better characterize the relationships between the two. Details of the relationships will support planning and evaluation of habitat actions under the BiOp. One of the most focused forms of this research is represented by Intensively Monitored Watersheds, which examine the results of concentrated habitat improvements at the watershed or population scale to assess changes in habitat and fish populations and the relationships between them. Most of the IMWs involve monitoring before and after the habitat improvement actions and include both treatment and control areas, an effective experimental design for detecting and measuring the benefits of habitat improvement projects.

The following section briefly describes the IMWs in the Columbia Basin, their central focus and results so far. In short, while IMW monitoring and analysis remain preliminary, the initial outcomes of habitat actions within



Planned monitoring in most Intensively Monitored Watersheds relative to the timing of treatments. Those with gray shading may not yield the same degree of population-level action effectiveness information. Dashed lines for pre-treatment monitoring indicate continued monitoring for untreated sites but not for treated sites. Dashed lines for post-treatment monitoring indicate monitoring of treated sites but not untreated sites. Dashed lines for treatments indicates uncertain timeframe.

IMWs suggest that grazing controls and in-stream improvements can create the expected improvements in habitat and fish numbers. That further suggests that large numbers of such actions across the landscape should translate into a population level effect that can be identified with greater confidence and precision as monitoring collects further data on recent habitat actions. Initial results from IMWs also provide increased confidence that ongoing research and monitoring can effectively detect the benefits of habitat improvements on a population scale.

Asotin Creek

Focus: Testing the effectiveness of riparian and in-stream wood improvements for increasing productivity of wild steelhead in Asotin Creek and determining the mechanisms that produce higher productivity. Monitoring focuses on habitat features and fish metrics designed to detect a population-scale response.

Results: Restoration treatments remain to be implemented. Pre-treatment monitoring documented that riparian areas are degraded but still providing significant shade and that both large woody materials and pools reflect less than half of reference values and therefore could prove to be limiting factors.

Entiat River

Focus: Assessing whether engineered log structures added to streams, channel reconnections and other habitat improvements increase habitat complexity and diversity enough to produce a population-level increase in salmon abundance or productivity. The structures are designed to create pools and off-channel habitat.

Results: Preliminary findings include increased numbers of pools and greater densities of juvenile Chinook and steelhead in pools created by the log structures during early summer (Entiat Intensively Monitored Watershed Report, 2012). Higher densities of juvenile Chinook appear to be associated with increased water depth around the structures. Both Chinook and steelhead favored pools around installed structures compared to others. Steelhead around installed structures also had higher growth rates. (See “Instream structures” in next section for more details.) Water temperatures have also declined since monitoring began more than a decade ago.

Potlatch River

Focus: Evaluate the response of steelhead populations to habitat improvements including large woody debris addition, culvert removals, riparian fencing and flow

augmentation. Early indications are that late summer rearing habitat is a limiting factor and that five years of monitoring will be required after improvement actions to detect changes.

Results: Not yet available

Lemhi River

Focus: Track densities, productivity and distribution of fish in the Lemhi River Basin and evaluate their response to habitat improvements, primarily the reconnection of tributary streams. Results will inform modeling to predict the benefits of future reconnections.

Results: Initial monitoring activities included habitat surveys, fish population estimates, redd counts and PIT tagging of juvenile salmonids in numerous locations. Monitoring has since expanded into a second phase that includes further PIT tagging, installation of PIT-tag antenna arrays, operation of an adult escapement weir and annual fish population sampling. Redd counts and surveys will document movement and spawning by anadromous and resident salmonids.

Most of the planned habitat treatments – mainly tributary reconnection and flow augmentation – have been or will soon be completed. The number of juvenile Chinook salmon produced per redd has increased, but the contributing factors remain subject to further data and analysis. Juvenile fish are now rearing in reconnected tributaries, but additional monitoring is needed to detect changes in productivity and other metrics.

Methow River

Focus: The Methow IMW design focuses on how projects influence habitat over a watershed scale to increase available food supply to listed salmonids in the context of a fish food web. The design strategy is to use models to guide the planning of field work as well as to support the analysis of projects and ultimately the redesign of treatments in an adaptive management framework. The effects of habitat projects on listed fish growth rates and survival will be placed in the context of a full-life cycle model. (Bureau of Reclamation 2013.)

Results: Researchers collected pre-treatment data and will conduct extensive data analysis and perform a model calibration in 2013 using the pre-treatment data. Post treatment monitoring begins in 2013, so early results will become available in 2014. An analysis of recent smolts-per-redd data indicates that freshwater is limiting juvenile salmon. Two BiOp studies have shown positive trends in fish abundance as a result of habitat improvement projects. An extensive monitoring effort in Beaver Creek after a fish barrier was removed has demonstrated the recolonization of wild steelhead spawners above the barrier. Monitoring of a levee removal and side channel reconstruction project at Elbow Coulee in the Twisp River shows an increased abundance of listed spring Chinook and steelhead in a now highly productive floodplain environment. Results of these and other projects will be analyzed for watershed-level effects.

Bridge Creek

Focus: Evaluate whether in-stream improvements produced by beaver dams can improve habitat by addressing stream incision and restoring floodplain connectivity, producing a population level improvement in fish productivity.

Results: Habitat actions improved habitat conditions by increasing pool frequency, area and depth. Fish survival and abundance increased. (For more details, see prior section, "Increasing fish survival and abundance follow habitat improvements.")

Upper Middle Fork John Day

Focus: Monitor habitat and fish response to in-channel restoration activities. Primary actions include re-meandering and wood revetments.

Results: Summer steelhead spawner abundance increased in the treatment area in the Upper Middle Fork of the John Day River from 2008 to 2011 while remaining static in the South Fork of the John Day, which is the control watershed. Further monitoring may more clearly indicate whether the increases result from the restoration actions.

Grande Ronde River

Focus: Monitor and document fish response to habitat improvements, using the results to characterize relationships between habitat actions and fish populations.

Results: See "Detailing the fish-habitat relationship" above for further details.

Okanogan

Focus: An intensive research and monitoring program focused on the Okanogan Basin closely resembles an Intensively Monitored Watershed. It is called the Okanogan Basin Monitoring and Evaluation Program, or OBMEP, and is operated by the Confederated Colville Tribes' Fish and Wildlife Department, with funding from BPA. The goals of OBMEP are to track the status and trends of summer steelhead and spring Chinook in the Okanogan Basin, identify the effects of habitat improvement actions on habitat and fish and assess the effects of fishery management. OBMEP also helped consolidate and coordinate piecemeal monitoring by various federal, state, tribal and other organizations.

Results: OBMEP has developed data collection procedures and infrastructure to document and track trends in habitat, spawning and juvenile and adult fish populations, with a goal of evaluating and improving the effectiveness of salmon recovery and restoration projects. Fish population data has demonstrated an increasing trend in returning adult summer steelhead. Habitat data supports a model which helps biologists and habitat managers understand and articulate the relationships between habitat and fish, identifying and targeting limiting factors. Habitat parameters are measured at 125 sites, with 50 sites visited annually and all sites visited every four years.

Removal of Hemlock Dam on Trout Creek in southwest Washington converted a warm pond blocked to fish (above, top) to a rushing creek with more natural characteristics of fish habitat (bottom). Native steelhead returned to the reopened creek in a matter of hours.

5. Assessing habitat benefits at the project level

Some of the most immediate evidence of the results of habitat improvements come from project-level action effectiveness monitoring and related studies, which reinforce the understanding of relationships between habitat quality and fish abundance. This section examines the effectiveness of different habitat improvement actions using three main information sources:

- Reviews of published literature on the effectiveness of various habitat actions.
- Effectiveness monitoring by the Salmon Recovery Funding Board (SRFB) in Washington and the Oregon Watershed Enhancement Board (OWEB) in Oregon
- Effectiveness monitoring under the BiOp and related programs.

The different sources provide various levels of information and detail. Two comprehensive reviews of the literature on the effectiveness of different habitat improvements have been completed in the last decade, with the first (Roni et al. 2002) largely assessing regional literature and the second (Roni et al. 2008) examining about 350 papers worldwide. These were supplemented by results of about 25 additional studies published since 2008 and reports from BPA project sponsors. Citations are included for readers' reference.

Meanwhile, SRFB and OWEB used standardized protocols to track different project categories so data could be combined for improved statistical rigor. For instance, the results of multiple projects from different categories can provide more evidence as to which ones yield more "bang for the buck" for the region and for fish.

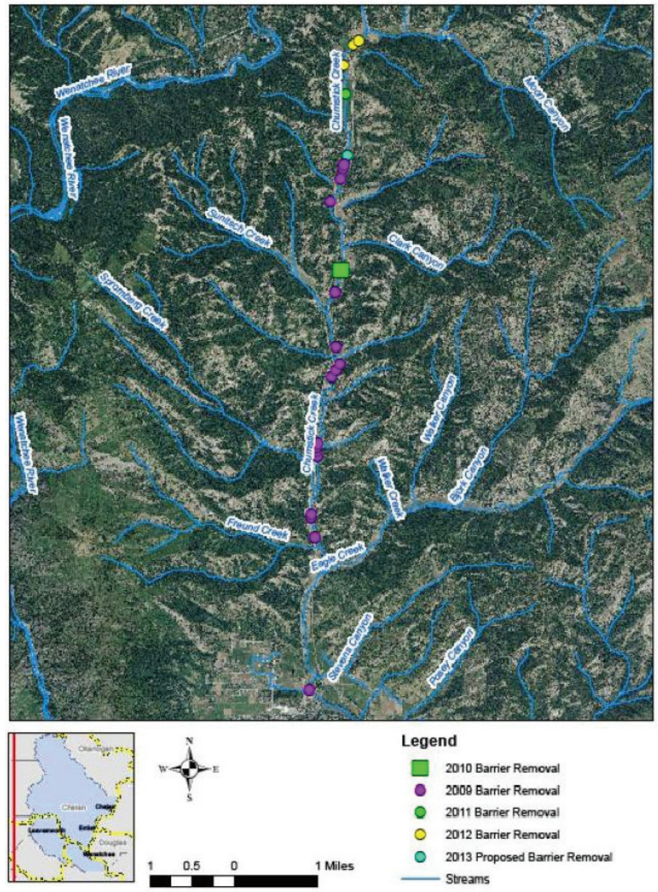
Finally, project monitoring under the BiOp and related programs is increasingly producing results that define the effects of habitat actions. Continued monitoring will add to the confidence of those results and will provide more detail and precision, especially when combined with larger scale data from ISEMP, IMWs and CHaMP.

The combination of sources provides strong evidence that established forms of habitat actions improve habitat conditions and benefit fish populations. The evidence is especially strong for passage improvements, in-stream improvements, reconnection of side channels, flow augmentation and controls on grazing.

Fish passage improvements

Summary: Research has documented benefits of improved fish passage through the removal of barriers and obstacles and screening of diversions that can otherwise entrain and kill fish. Fish are known to rapidly colonize newly accessible habitat, expanding their numbers into new geographic areas.

Literature: Reviews and monitoring have consistently reported barrier removal or installation of new or improved fish passage as one of the most effective and highest priority habitat improvement measures for salmon and steelhead. Studies have shown that fish rapidly colonize previously blocked or less accessible areas, usually as a function of distance from the source population (Burdick & Hightower 2006; Stanley et al. 2007, Roni et al. in press; Roni et al. 2008; Zitek et al. 2008; Pess 2009; Nakamura & Komiyama 2011). For example, installation of a fish passage structure on a diversion dam on the Cedar River in Washington led to the recolonization of newly accessible habitat by both juvenile and adult salmon and steelhead within five years (Pess et al. 2011). Similarly, Martens and Connolly (2010) demonstrated movement and recolonization of Chinook salmon and steelhead after improved passage at irrigation diversions in the Methow Basin. Most studies have focused on complete removal of barriers. Replacing partial obstructions can also be successful but is not as commonly studied.



Impassible culverts and other barriers removed from Chumstick Creek, opening about eight miles of habitat.

In eight of nine projects, SRFB/OWEB monitoring found juvenile fish, spawners and redds upstream of the previous barrier within three years after its removal. Analyses also found that the density of juvenile salmon and steelhead had increased more than 20 percent above baseline by the fifth year after removal of the barrier, one of the criteria for effectiveness of such projects.

Examples: Passage improvements under the BiOp and related programs have demonstrated similar success. In 2009, the Chelan County Natural Resource Department replaced 16 culverts blocking fish passage on Washington's Chumstick Creek with bridges passable to fish, using funding from BPA and the Columbia Basin Fish Accord with the Yakama Nation. Another culvert was replaced with a combination of funds. The changes opened rearing habitat for Chinook and spawning and

Wild adult steelhead six miles up Chumstick Creek after barrier removals.

rearing habitat for steelhead and coho. Additional barriers were replaced through 2012, opening eight miles to fish passage. In 2011 PIT tag arrays mounted on a bridge detected 41 adult and 30 juvenile steelhead, including 20 wild adults and four wild juveniles, in the formerly obstructed areas. In 2012 the arrays detected 37 adult and 10 juvenile steelhead, including 11 wild adults and seven wild juveniles. Only tagged fish were counted, so the true number may be higher.

Screening diversions

Summary: Hundreds of irrigation diversions across the Columbia Basin have been screened to prevent fish from becoming entrained or drawn into irrigation ditches, where they typically become stranded and die. Effective screening addresses a clear and significant source of juvenile mortality.

Literature: Most monitoring of screening improvements focuses on whether the screens are working as intended to prevent entrainment of fish, and in most cases has found that they are. One of the most thorough studies of the potential impact of entrainment and the benefits of screening (Walters et al. 2012) examined the Lemhi River in Idaho, which is home to listed salmon and steelhead but is heavily diverted for irrigation. Walters et al. used PIT tag records to track the potential losses at six diversions. They used the data to develop a model that could be applied to all diversions and estimated that under median streamflow conditions with no screens, approximately 71 percent of Chinook salmon smolts would be lost to entrainment at the 89 diversions they encounter during their migration out of the Lemhi.

However, the research demonstrated that screening is a highly effective mitigation strategy that could reduce cumulative mortality to about 2 percent with all diversions screened. Most major diversions in the Lemhi have indeed been screened through programs funded by the Action Agencies and other organizations, so much of the modeled survival improvements have probably been realized (A. Walters, personal communication). The authors concluded that the approach could be used to compare the costs and benefits of various screening options to help managers prioritize the most cost-effective choice. The authors noted, however, that the study assumed a high survival rate for fish protected from diversions by screens, which may not account for stress or other unquantified impacts of the screens.

Example: A program in the John Day Basin manufactures, installs and services fish screens designed to protect wild populations of Chinook salmon and steelhead in the John Day, Umatilla and Walla Walla subbasins. The program works in cooperation with public and private landowners and managers, irrigation districts and others to install approximately 15 to 25 new and improved screens annually. For example, in September 2011 BPA provided most of the funding for a solar powered traveling belt screen to replace a former screen that no longer met state and federal criteria and was difficult to maintain (ODFW undated). Fry could be drawn through the old screen or become trapped on it.

The improved screen better protects endangered summer steelhead, bull trout, redband trout and other non-game fish.

Instream structures

Summary: Addition of in-stream structures such as logs and rocks is one of the most established, widely accepted and most well-studied forms of habitat improvements. Most studies have found a positive response by juvenile salmonids and those that did not were probably hampered by their short time frame or failure to consider watershed processes.

Literature: Structures such as logs, logjams, cover structures or boulders to streams are known to help increase pool area and habitat complexity, providing refuge and supporting food production for juvenile fish. Most published studies on the effectiveness of habitat improvements have focused on this type of improvement, with many studies reporting increases in pool frequency, depth, woody debris and other habitat qualities important to fish (Crispin et al.1993; Bates et al. 1997, Binns 1999; Gerhard and Reich 2000; Roni and Quinn 2001a; Negishi and Richardson 2003; Brooks et al. 2004). While a variety of factors can affect the level of response, many in-stream structures lead to substantial improvements in physical habitat such as complexity, depth and channel conditions as well as in retention of organic matter important to food production (Roni et al. 2008).

Recent literature reviews indicate that where installed correctly, in-stream structures benefit juvenile Chinook, coho and other species and life stages that prefer pool habitats (Roni et al. 2008). Constructed logjams have been shown to be particularly beneficial for juvenile Chinook, steelhead and coho (Roni et al. 2002; Pess et al. 2012). Monitoring of logjams in the Grays River, a tributary of the lower Columbia, recorded increases in pool area, habitat complexity and fish numbers following installation. The structures have also been shown to trap organic material and boost production of aquatic insects, providing additional food for fish (Coe et al. 2006). Several studies have also found benefits for spawning Chinook salmon and steelhead (Merz and Setka 2004; 2008).

Example: Monitoring of the Entiat IMW under the BiOp observed more juvenile Chinook salmon using pools created by log restoration structures, apparently responding to the increased water depth around the structures (Entiat IMW Report, 2012). Also fish captured in the pools remain in the area longer than fish at control sites that were left alone. This can prove positive for fish because juveniles that remain in one area longer conserve energy and reduce their exposure to predation, which will in turn increase their growth and survival.

Steelhead at Entiat restoration sites did not show a similar increase in density, but had higher growth rates, indicating that factors other than density should also be examined for potential responses. Growth and survival are also important in helping account for the preferences of different species in how they use the river.

Off-channel/floodplain habitat improvement

Summary: Reconnection and improvement of off-channel habitat may include reconnecting existing side channels or wetlands or constructing new ones. It may also include relocating levees to allow more natural stream behavior and characteristics. Studies indicate that side channels have untapped capacity to support salmonids and have consistently shown that salmonids quickly recolonize such newly accessible habitat as they do following barrier removals.

Literature: Reconnected floodplains, ponds, side channels and wetlands have proven effective at providing habitat for juvenile salmonids (Richards et al. 1992; Roni et al. 2002, 2006, 2008; Henning et al. 2006). Removing or modifying levees can lead to wider, more active floodplains and increased connectivity between rivers and their floodplains as a function of increased surface

Crews reconnect an oxbow side channel to Nason Creek in 2007.

and subsurface flow and improved riparian and aquatic diversity (Jungwirth et al. 2002; Muhar et al. 2004; Konrad et al. 2008). This can lead to improved productivity in new or reestablished habitats that increase food resources for fish (Schemel et al. 2004; Ahearn et al. 2006). Fish rearing in such habitat often demonstrate higher growth rates (Sommer et al. 2001).

A study of food webs on the Methow River in Washington found that anadromous salmonids that are the focus of habitat improvements faced less competition for food in side channels, which had on average 251 percent higher carrying capacity for salmonids than the main channel (Bellmore et al. 2013). The study concluded that side channels could support much larger populations of salmonids, which would benefit from actions that support natural processes that promote habitat complexity in the floodplain.

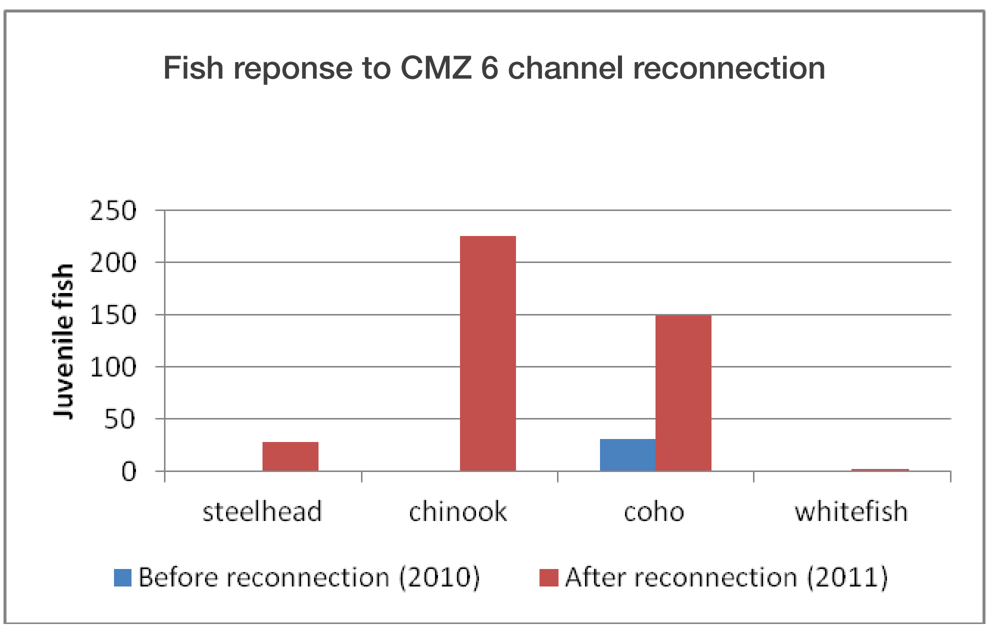
Constructed ponds and side channels have been shown to provide habitat for juvenile fish and can improve overwinter survival (Lister and Bengeyfield 1998; Solazzi et al. 2000; Giannico and Hinch 2003; Roni et al. 2006). Monitoring of a constructed side channel on Duncan Creek, a tributary of the lower Columbia, showed high levels of chum egg-to-fry survival in the range of 50 to 85 percent and ideal spawning and incubation conditions (Hilton 2010). SRFB/OWEB monitoring found rapid increases in use of two projects in the upper Columbia by Chinook salmon in the year following construction.

A cost-effectiveness analysis of SRFB/OWEB projects found that floodplain enhancement projects were among the most cost-effective projects for increasing juvenile Chinook, coho and steelhead densities and underscored the connection between the availability of pools and increased juvenile salmonid densities.

Example: In 2007, the Chelan County Natural Resources Department installed two passable culverts to reconnect a 3,500-foot channel that had been cut off from Nason Creek by highway construction in the 1950s. Within a year hundreds of juvenile salmon and steelhead had returned to the reopened habitat, as documented by monitoring crews from the Yakama Nation and Washington Department of Ecology (Michael Kane, Chelan County Natural Resource Department, personal communication, 2012).

Another similar project in 2010 improved a 200-foot outlet channel and constructed a 650-foot side channel on the Wenatchee River with BPA funding, with the goal of providing off-channel refuge and rearing habitat for juvenile steelhead and spring and summer Chinook salmon. Water flows through the upper section of the CMZ 6 side channel during high spring flows and flood events, while the lower half of the side channel remains connected year-round. Counts prior to the habitat improvement project found very few salmon using the channel, while a Yakama Nation monitoring crew counted many more salmon in August 2011. Salmonid use during the spring and early summer is believed to be much higher than shown for the 2011 counts (Kane 2012).

Floodplain and side channel reconnection projects also provide benefits through more natural flood flows and pulses that deliver water to essential habitat. For example, the Bureau of Reclamation designed the 2008 reconnection of a side channel to the Twisp River that had long been cut off from natural river influences including



high spring and winter flows known to improve habitat conditions and diversity. High flows soon activated the side channel for the first time in more than 50 years (Bureau of Reclamation 2012).

Subsequent monitoring has found that high water has reactivated the side channel each year, with juvenile spring Chinook and steelhead observed using the side channel following nine high-water events spanning 284 days over three years. A survey in late 2011 recorded an almost three-fold increase since 2008 in fish abundance and increased species diversity, with endangered Upper Columbia spring Chinook juveniles increasing in number from one fish to 48 and steelhead more than doubling from 34 to 74. Habitat complexity has also improved through increased pool habitat, wetted width of the channel and increased large woody material (Bureau of Reclamation 2012).

Riparian improvements

Summary: Improvements to riparian areas may include fencing for protection from livestock grazing, plantings and removal of invasive species or some combination of these and other actions. Studies have found significant improvements in habitat conditions and fish density following construction of exclosures or other grazing controls. However, other riparian improvements may take many years to significantly improve habitat conditions or produce favorable fish responses.

Literature: Several studies have examined the effectiveness of riparian fencing and other controls on livestock grazing and most of them have documented improvements in riparian vegetation, bank erosion, channel width and sediment levels, especially with livestock exclusion (Platts 1991; Roni et al. 2002, 2008; and Medina et al. 2005). Rest-rotation grazing is generally less successful than complete exclusion of livestock and results depend on livestock densities, rest periods and the degree of livestock management. Fish responses to rest-rotation grazing have been highly variable, with a few studies showing positive responses from rainbow and other trout (e.g. Keller and Burnham 1982; Li et al.1994; Kauffman et al. 2002).

BPA-funded studies of grazing exclosures in the John Day Basin found a highly significant 2.5-fold average increase in the density of age-0 juvenile redband trout in reaches protected from grazing (Bayley and Li, 2008). The research attributed the greater density to the improved food supply and cover related to improved undercut bank conditions, riparian vegetation and width-to-depth ratio. The study concluded that the results were promising but the exclosures examined were too small and too few to produce demonstrated population level benefits.

SRFB/OWEB monitoring of livestock exclusion projects found statistically significant improvements in bank erosion and riparian vegetation structure across all livestock exclusion projects examined. Bank erosion has consistently decreased by more than 20 percent from year to year, an improvement from pre-project conditions.

Given the long time required to detect a response to riparian planting, most monitoring of riparian planting has examined short-term survival of planted species (Pollock et al. 2005; Roni et al. 2008). Several BPA-funded projects that have monitored plant survival have shown high survival rates greater than 60 percent and increases in shade in the first few years following planting. For example, survival of planted vegetation averaged 97 percent for ponderosa pine and 70 percent for white oak in the Klickitat Basin in the first year after planting (Yakama Nation Fisheries Program 2009).

Only a few short-term studies have examined the response of fish to riparian treatments and have produced varying results depending on the region and treatment (Penczak 1995; Parkyn et al. 2003). Most riparian treatments influence reach-scale conditions, while in-channel conditions are more often affected by upstream or watershed-scale features, which may limit the biological response in the project area. However, riparian treatments and restoration are often critical to the success of other projects such as in-stream or floodplain improvements. For example, riparian planting and grazing controls can improve shade, bank stability, and water quality. All those factors can influence the success of in-stream habitat improvement projects.

Example: An ambitious stream restoration project in the Methow Valley of northern Washington funded in part by BPA and led by the Yakama Nation is examining the effects of several habitat improvement strategies on riparian conditions and fish populations (John Jorgenson, personal communication, 2012). Hancock Springs fed a creek that had become badly degraded by gazing and other impacts

Hancock Springs as a wide, shallow and barren expanse prior to habitat improvements (above,top) and after (bottom), with more natural stream contours, habitat complexity and deeper pools.

to the point that much of the riparian vegetation had disappeared and little creek channel remained. Biologists from the Yakama Nation in cooperation with local groups and agencies began installing fencing and adding in-stream structures to restore pools and spawning riffles. Fish that had been absent for years began returning to spawn – first steelhead in 2007 and then, in later years, endangered upper Columbia spring Chinook.

The project includes detailed monitoring to track the effects of habitat actions including in-stream improvements, nutrient additions and removal of non-native species and their effect on the aquatic food web, as suggested by the ISAB (ISAB 2011) and in recent literature (Naiman et al. 2012). Actions at Hancock Springs in 2011 include riparian planting, channel excavation and reconfigurations and the addition of large woody debris and other structures. Although fish were excluded from the restoration area in 2011 to allow for construction, afterwards they returned at a greater rate to the improved reach of the creek compared to the control area that was left largely unimproved.

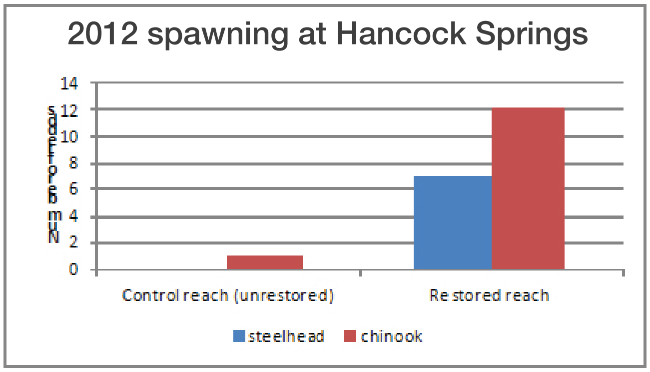
Future plans at Hancock Springs include nutrient enrichment to boost marine nutrients once brought back from the ocean by spawning salmon, which nourished the food chain, and potential removal of non-native brook trout. Research and monitoring will examine the influence of the various treatments on fish populations and the broader food web individually and in combination (Yakama Nation Fisheries 2013).

Flow augmentation/improvement

Summary: Supplementation or restoration of in-stream flows is an important form of habitat improvement and studies have clearly documented improvements in production of fish and macroinvertebrates that fish depend on for food.

Literature: Restoration of in-stream flows is a key habitat improvement strategy in the Columbia Basin with clear benefits for salmon and other fish that require sufficient water quality and volume to live and reproduce. Literature has shown that increases in flow translate into increased fish and macroinvertebrate production (Weisberg and Burton 1993; Gore et al. 2001; Lamouroux et al. 2006), with the most dramatic responses in stream reaches that had endured very diminished flows with warming temperatures (Sabaton et al.2008; Roni et al.2013). Restoration of natural flows, whether base flows or flood pulses, is essential to many habitat improvement projects such as riparian plantings and floodplain reconnection.

Example: Little Springs Creek is a spring-fed tributary of the Upper Lemhi River that provides rearing habitat for juvenile chinook salmon, steelhead and other species. However, several diversions often left it dry and disconnected from the Lemhi during much of the irrigation season. The Idaho Water Resource Board worked with other agencies to reconnect Little Springs Creek to the



Lemhi through a series of projects in 2011 that moved diversions to reduce impacts on the creek and keep its cool spring water flowing. Little Springs Creek is now fully reconnected to the Lemhi and its water quality is improved. The flow improvements were accompanied by fencing, replacement of outdated culverts and channel restoration. A PIT tag array detected 15 wild steelhead in the creek in 2011 and 29 wild steelhead and three wild chinook in 2012. Steelhead were observed spawning in the stream in 2011 (Idaho Department of Water Resources, personal communication, 2013).

Idaho Fish and Game biologist Jeff Diluccia observes a steelhead redd in Little Springs Creek, a recently reconnected tributary of the Lemhi River. Photo by Jerry Myers, Trout Unlimited.

Land acquisition and protection

Summary: Protection of high quality habitat through acquisition or conservation is a critical element of most habitat protection strategies and may be a necessary precursor to improving riparian or in-stream habitat. Studies have demonstrated that habitat protection generally is effective in protecting water quality. Protecting habitat is generally far more cost-effective than restoring habitat after it has been degraded.

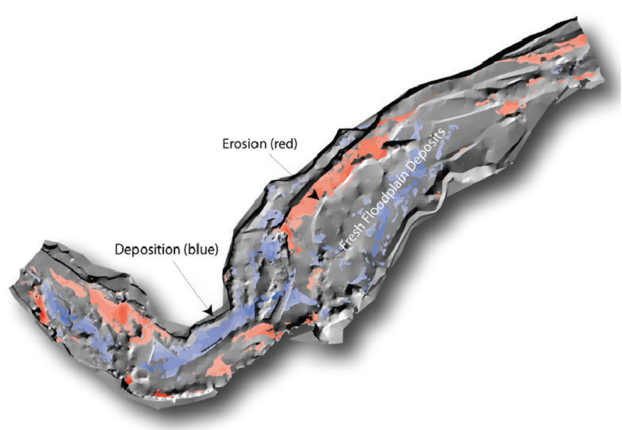
Literature: Most monitoring of protected habitat involves status and trend monitoring meant to assure that the habitat recovers or does not further deteriorate. In some cases, protection of habitat is essential in supporting natural river or stream processes such as functioning floodplains that in turn create and improve habitat for fish. It is also typically cheaper and more effective to protect high quality habitat with properly functioning ecosystem processes than to attempt to restore or recreate such processes in damaged habitat, which can take decades or more.

Most published studies of habitat protection actions have focused on protection of riparian buffers and have generally indicated that protecting such buffers can reduce sediment, nutrients and pesticides reaching streams and to improved bank stability and water quality (Osborne & Kovacic 1993; Barling & Moore 1994; Dosskey et al. 2005; Mayer et al.2005; Puckett and Hughes 2005; Vought and Loucosiere 2010). Habitat protection can be considered a kind of "passive restoration" that allows ecosystems to recover and repair themselves through natural processes (Roni and Beechie, 2013)

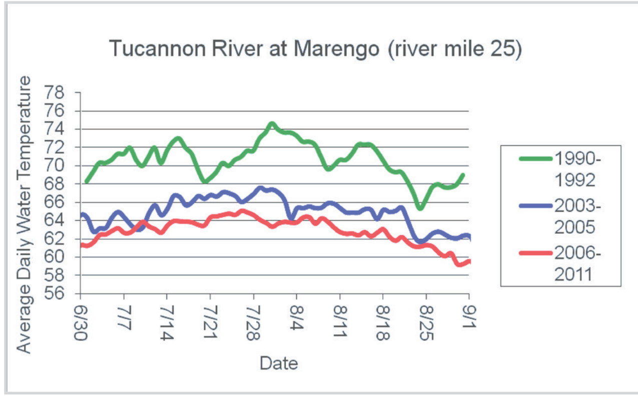
SRFB and OWEB monitoring of seven habitat protection projects found habitat quality to be stable or improving, with indications of maturing upland vegetation that is a sign of improving habitat conditions. Indexes of macroinvertebrate communities and fish diversity both indicated favorable conditions at most sites, evidence that they support high quality habitat that is remaining stable over time.

Example: In 2008 BPA funding supported the extension of an easement compensating landowners for not farming or otherwise developing a stretch of the Tucannon River floodplain. The easement was designed to both protect existing habitat and to provide the river room to allow for natural processes that improve habitat. For example, natural river processes can in the right circumstances create deeper pools and slow-water refugia and reestablish floodplain connectivity. While such natural habitat improvement may come more slowly than constructed improvements, it can also prove far more cost-effective (Steve Martin, Snake River Salmon Recovery Board, personal communication, 2013).

Digital elevation maps collected by CHaMP indicate that the natural river processes are improving. The maps over time reveal areas of erosion and deposition, indicating that the river is evolving into more favorable habitat for fish (Martin 2013). The results provide increased confidence for local managers that the easement is promoting the anticipated improvements and that no further action is currently necessary. In that way, the research and monitoring results are informing local decisions on habitat actions.



Digital elevation map of the Tucannon River indicating areas of deposition (blue) and erosion (red), which is informing decisions.



Average daily summer water temperatures measured at about the mid-point of the Tucannon River show a declining trend since 1990. Data analysis by Steve Martin, Snake River Salmon Recovery Board.

An examination of water temperatures in the Tucannon River over the past 25 years indicate that a trend of decreasing temperatures has accompanied expanded habitat improvement actions. Habitat actions in the Tucannon began to a limited extent in the early 1990s and provided riparian buffers in the late 1990s. Actions to address erosion and riparian conditions expanded through the 2000s and by 2009 included aggressive stream channel restoration. Temperature data indicates an average decline of about 6 degrees in the river's water temperature over that period into a more favorable range for fish. While the data does not conclusively prove that habitat actions in the Tucannon caused the temperature decline, it does underscore an association between concerted habitat improvements across a watershed and improving conditions for fish.

Bringing it all together

Although many habitat improvement projects include a variety of habitat actions, the kind of experiments and research underway on Bridge Creek and at Hancock Springs are teasing apart the benefits of specific types of actions. The most easily detected benefits and clearest responses from fish in the short term result from actions that address clear physical or biological impediments such as impassable barriers, disconnected side channels or lack of sufficient flow. Such impediments also often coincide with pronounced limiting factors for fish. Salmonids rapidly colonized newly accessible areas that typically provide more habitat diversity, a benefit which will help address the

risk of climate change affecting temperatures and flows in coming decades.

The clearest and most immediate results often come from those experiments or IMWs that pursue only a few limited types of habitat actions, since the relationships between habitat factors and fish numbers are subject to fewer variables. Studies pursuing a broader range of habitat actions may be less able to discern the influence of each habitat action but can track population-level responses on a larger scale. While the results from IMW research will expand with time, initial findings have already begun to inform the design and development of upcoming habitat improvement projects.

Incorporating lessons learned from past projects and research

Most of the examples described would be considered successful instances of habitat improvement or research, in that they benefited fish or, in the case of research, more clearly revealed how to achieve such benefits. This is not to say that every habitat improvement project and related research produces the expected results. Roni and Beechie (2013) describe reasons why habitat improvements might not produce the anticipated response or research might not detect the response, including:

- Habitat actions might not effectively address the root cause of habitat or water quality degradation.
- Actions might not be appropriately designed for the local conditions.
- Monitoring might not be sensitive enough or continue long enough to record a response.

For example, Frissell and Nawa (1992) reported that in-stream structures in southwest Oregon and southwest Washington failed at a high rate following flooding because they were not designed for local conditions already affected by landslides and erosion. Several authors (Chapman 1995, Roni 2008, Doyle and Shields 2012) have noted that in-stream improvements cannot by themselves overcome larger, watershed-scale problems that degrade in-stream habitat. For instance, Larson et al. (2001) found that adding wood to urban streams produced little biological improvement, likely because of development and other disturbance in the larger watershed. Some researchers (Rinne 1999; Johnson et al. 2005) indicated that insufficient study designs or limited monitoring kept them from detecting the results of habitat improvements. For instance, Johnson et al. (2005) concluded that a poor match between their treatment and control streams hampered their detection of significant changes in coho and steelhead survival.

Recent literature (Roni and Beechie 2013; Roni et al. 2008; Beechie and Bolton 1999) has stressed the need for restoration in a watershed context and for comprehensive and rigorous monitoring. The BiOp's habitat improvement and RM&E programs were designed with this in mind; both are likely among the largest, most sophisticated and most detailed of their kind. They also include a clear adaptive management provision that will adjust strategies to new information, which has proven successful in other habitat improvement programs (Pierce et al. 2013).

Adaptive management is improving the effectiveness of habitat actions as the Action Agencies and regional partners incorporate recent RM&E results such as those described here to improve planning, development, prioritization, implementation and monitoring of upcoming habitat improvement projects. The Action Agencies also provide teams of specialists including biologists, geomorphologists and engineers to work with watershed partners to understand river processes and incorporate the latest science into the identification and development of sustainable habitat improvement opportunities.

6. Adapting and Improving RM&E

The importance of RM&E in documenting and tracking progress on behalf of the region's fish and wildlife populations and the large amount of federal and regional ratepayer funds devoted to it have led to appropriate scrutiny from the Northwest Power and Conservation Council and others, with accompanying recommendations for improvement. The Action Agencies have already adopted some of the recommendations and are in the process of pursuing others. The more effective, efficient and reliable the research and monitoring is, the better it will inform habitat improvement efforts. This section of the report briefly describes recommendations for improvement in the RM&E program and how the action agencies are addressing them.

In addition, the scientists who contributed to sections of this report also provided recommendations for strengthening research and monitoring programs and protocols. These recommendations are under consideration or implementation, and attached as Appendix A.

The RM&E program itself is fully designed and intended to be adaptive, adjusting and improving based on experience and lessons in terms of the approaches that deliver the most useful results. The Action Agencies will consistently assess their RM&E program and the results it provides for potential improvement. At any one time the RM&E framework should provide managers and others with data and analyses representing the best available science but will also strive to improve and advance that science over time to provide even more informative and useful results in the future.

The following is a list of major recommendations from the Council and the Independent Scientific Review Panel, with descriptions of how the Action Agencies are responding.

Develop a framework that clearly describes the components of the RM&E program. A new framework document presented to the Council in early 2013 contributes to this goal. A separate estuary framework document is also in development.

Standardize annual reporting by project sponsors. In 2012 BPA introduced a standard reporting template that all project sponsors will use to submit their annual reports. The more consistent format and timing will simplify analysis and synthesis of data, providing more useful and far-reaching results and guidance for decision-makers and managers. While the ISRP voiced some cautions, the Action Agencies believe they can be addressed by phasing in changes and considering lessons learned.

Standardize data collection. Traditionally project sponsors each developed their own monitoring approaches for their habitat improvement actions, resulting in varied studies that monitored different habitat conditions and tracked different metrics using different techniques. This often meant that the data and results were incompatible, unfortunately limiting their use. BPA continues to work toward program and region-wide standards for data collection and sharing. Project level implementation metrics are standardized under BPA's contract reporting system. Methods for monitoring now require standard documentation using monitoringmethods.org. Advances continue through ongoing support for the Pacific Northwest Aquatic Monitoring Partnership tools for standard metadata (data documentation), monitoring designs and data exchange templates.

Consider using a single third party for monitoring. A pilot effort is underway in the Upper Columbia to use a third-party monitoring program for implementation and compliance monitoring. In addition, third parties will also be used to provide additional quality assurance and control, ensuring unbiased monitoring results.

Set realistic timeframes. The ISRP advised the Action Agencies to set realistic expectations for when useful results can be expected from the RM&E associated with habitat protection and improvement efforts. This is a particular challenge because while managers want useful results as soon as possible, habitat improvements may take years to provide full benefits and RM&E may take time to detect quantifiable changes. The Action Agencies are addressing this in several ways. First, standardized measurements and reporting should produce clearer and more useful results sooner. Second, the scaled approach of the different elements of the RM&E Program should provide managers with detailed results on individual projects through project action effectiveness monitoring while also folding that information where possible into higher-level analysis that should provide timely, if less detailed, results at a larger scale. Because of the natural variables at work on large scales, however, higher resolution results will require more data and more time.

Make data more accessible. BPA will improve the accessibility and management of fish and wildlife habitat data by implementing the elements of its data management strategy, "A Framework for the Fish and Wildlife Program Data Management: Issues and Policy Direction for Development of 2013 Data Management Strategies and Action Plan." This approach will help standardize methods and data exchange templates and integrate different data management systems so researchers can more easily access a wider range of data, much of it online.

7. Conclusion: Putting research into practice

Scientific literature, the experience of other habitat improvement programs and emerging evidence from the Columbia Basin provides increasingly strong evidence that improvements in habitat quality translate into improved fish survival and abundance. While the specific mechanics require further definition and may vary between species and watersheds, the bottom line is that actions such as barrier removal and side-channel reconnection designed to directly address physical and biological impediments yield positive results for fish in a relatively short timeframe. Other actions such as riparian improvements designed to improve reach or watershed-scale processes may not produce such rapid responses from fish but often remain essential ingredients in the long-term success of the more pronounced in-channel actions.

Evidence of habitat factors most important in determining fish density and abundance combined with evidence of the most effective habitat actions will help managers make the best investments for fish and for the region. The action agencies are working with project sponsors to readily share and exchange such research findings so they can inform and guide development of future habitat actions.

Key emerging RMRE results	
Habitat attributes most important to fish density	Flow, pool number and percentage, pool depth, gravel type, temperature
Most effective habitat actions	Barrier removals, reconnections, flow restoration/augmentation, riparian restoration and in-stream improvements
Large-scale response to habitat improvements	Correlation between fish survival and low-impact land use, fewer roads and higher concentration of habitat improvement projects

Large-scale studies that examined the relationships between habitat improvements and habitat quality as documented by PIBO and other programs in the Snake River Basin found many relationships between the two, underscoring benefits of habitat improvement that until recently had been largely documented outside the Columbia Basin. Large numbers of habitat improvements correlated with a roughly 20 percent increase in parr-to-smolt survival, while further analyses showed that about 23 percent of the variation in fish length and 13 percent of the variation in survival could be explained by PIBO habitat measurements. Taken together, the results suggest that habitat and fish data collected by IMWs, CHaMP, PIBO, and similar efforts show a linkage with the performance of listed stocks in streams where the fish spawn and rear.

From the limited scale of individual projects to the larger scale of watersheds and populations, project managers in the Columbia Basin are now better positioned to identify factors influencing and limiting fish abundance and survival and design habitat projects to target them. The results of the RM&E program thus far also provide increased confidence that the benefits of habitat improvements can be detected and measured on small and large scales as fish respond over the short and long term.

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APPENDIX A: Recommendations for RM&E improvements

The following recommendations were developed by Tim Beechie, George Pess, Phil Roni of the Northwest Fisheries Science Center, Jennifer O'Neal of TetraTech and Tracy Hillman of BioAnalysts, Inc. The Action Agencies are reviewing the recommendations and steps to address them are underway.

Project-level Action Effectiveness Monitoring

Modifications to existing BPA project level effectiveness monitoring including:

1. A coordinated multiple BACI monitoring approach to evaluate average response of different project types similar to that being implemented by SRFB/OWEB but with larger sample size, improved stratification by project type and two or more years of pre-project data.
2. Focused "case studies" to evaluate new techniques or project types that are relatively rare.
3. Post-treatment assessment of project types that do not require pre-project data to provide a near-term assessment of effectiveness of previous projects (e.g. barrier removal, fencing).
4. Improved data management and reporting for existing BPA project level effectiveness monitoring to provide consistent results that can be analyzed across projects.

These four modifications or existing BPA project level effectiveness monitoring program coupled with an ongoing IMW program should assure a comprehensive program for evaluating habitat and survival improvements due to restoration at a project, reach and population level.

Population-level Action Effectiveness Monitoring

Primary recommendations address how the data will be used to inform planning and evaluation of BiOp projects and the simplification of reporting to clearly distinguish IMW results from status and trends or project-scale action effectiveness. Specific recommendations are:

1. Clarify how results from each of the IMWs inform monitoring and evaluation of restoration actions and selection and design of future projects.
2. In addition to clarifying how each IMW contributes to the broader goal, it is also important to examine whether the ad hoc collection of IMWs and experimental designs can be leveraged to provide more generalized results, or whether each IMW is simply a stand-alone experiment.
3. Reporting would be much more useful if status and trends, population-scale effectiveness, and project-scale effectiveness were treated separately. It is currently very difficult to distinguish them and to understand whether or how any of the studies effectively address the four questions above. It would be helpful if there were some general reporting guidelines for the IMWs so that each report can briefly provide important information. Alternatively, it would be good to clearly state the role of each monitoring study in answering key management questions for the BPA.
4. Habitat Status and Trends

Specific recommendations include:

1. Habitat status and trend monitoring programs should continue to be implemented over time so they can accurately identify habitat concerns and trends.
2. The programs should develop tools that clearly display habitat conditions throughout a population (e.g., habitat quality distribution maps) and identify what factors contribute to different levels of habitat quality or properly functioning condition.
3. The programs should determine the best way to translate habitat metrics into indicators of fish performance.
4. Because habitat monitoring cannot occur within every population in the Columbia Basin, it is important to develop methods that allow results from one population to be used to help understand habitat conditions within another population.
5. CHaMP and PIBO should compare habitat monitoring results within a select few watersheds as a step toward better program integration and coordination.
6. Habitat monitoring programs should determine if they are measuring and tracking habitat indicators that limit fish survival and productivity. If an indicator does not explain fish survival or productivity, there is no need to continue to measure it.

BONNEVILLE POWER ADMINISTRATION

BUREAU OF RECLAMATION

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