EFFECT OF STREAM RESTORATION ON THE HABITAT POTENTIAL OF JOHNSON CREEK, PORTLAND, OREGON, FOR COHO, FALL CHINOOK, AND WINTER STEELHEAD

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Acronyms and Abbreviations

cfs	cubic feet per second
City	City of Portland
DPS	Distinct Population Segment
EDT	Ecosystem Diagnosis and Treatment
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
I	Interstate
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
WPA	Works Progress Administration

Project Context

The City of Portland (City) has made significant commitments to the restoration of the Johnson Creek watershed. The City has made these investments to provide ecosystem services such as flood control and water quality, to contribute to recovery of salmonid populations listed under the federal Endangered Species Act (ESA) and to enhance the quality of life for Portland residents (City of Portland 2005). Johnson Creek and its tributaries comprise the largest stream system within the City's jurisdiction, and are, therefore, of key importance to issues such as salmonid recovery and stormwater management (Meross 2000).

To achieve these goals, the City has undertaken major stream restoration efforts to restore conditions affected by urban development in the lower Willamette River and key tributaries including Johnson Creek. The direction and prioritization of these investments has been supported by scientific studies and analysis aimed at understanding the potential of Portland's urban streams and to identify habitat limitations and opportunities. A key component of these tributary studies has been the assessment of conditions to support strategic investments in habitat restoration and protection actions. This has included in-depth studies of fish assemblages and habitat use in the lower Willamette River (Friesen 2005) and tributaries including Johnson Creek (ODFW 2000; Graham and Ward 2002). The City has synthesized much of this information to create an analytical framework for assessment of Portland streams and identification of limiting factors and priorities (McConnaha 2003; Primozich 2004). The City's analytical framework has been applied to the assessment of conditions in Johnson Creek (McConnaha 2003) and to the evaluation of restoration efforts in Tryon Creek (ICF Jones & Stokes 2008). These efforts have provided an understanding of the ecological potential of these streams and have helped the City plan and prioritize restoration actions. The analytical framework has also quantified habitat potential of the streams and identified its key role in recovery of ESA-listed salmonid populations in the lower Willamette River.

In this report, we analyze and compare the impact of restoration projects in Johnson Creek on the habitat potential to support native salmonid fishes. To do this, we compare the habitat potential at two points in time, 2000 and 2009. During this period, the City undertook several major stream restoration actions in Johnson Creek to provide flood control, enhance the natural character of the stream, and to contribute to restoration of ESA-listed coho salmon, winter steelhead and Chinook. In this analysis we have assessed the potential biological value of these projects and quantified the contribution of the City's efforts to restoration of ESA-listed salmonid populations in the lower Willamette River. The analysis also serves as a tool to evaluate restoration priorities and recovery actions in Johnson Creek to continue progress toward the City's ecological goals for Johnson Creek.

The analysis will be reported in two separate reports. This report will analyze and compare four major stream restoration efforts in Johnson Creek undertaken between 2000 and 2009. A second report will provide a new diagnosis of conditions in Johnson Creek in light of the changes that occurred over the 2000–2009 period and evaluate the biological priorities and needs for the stream under current conditions.

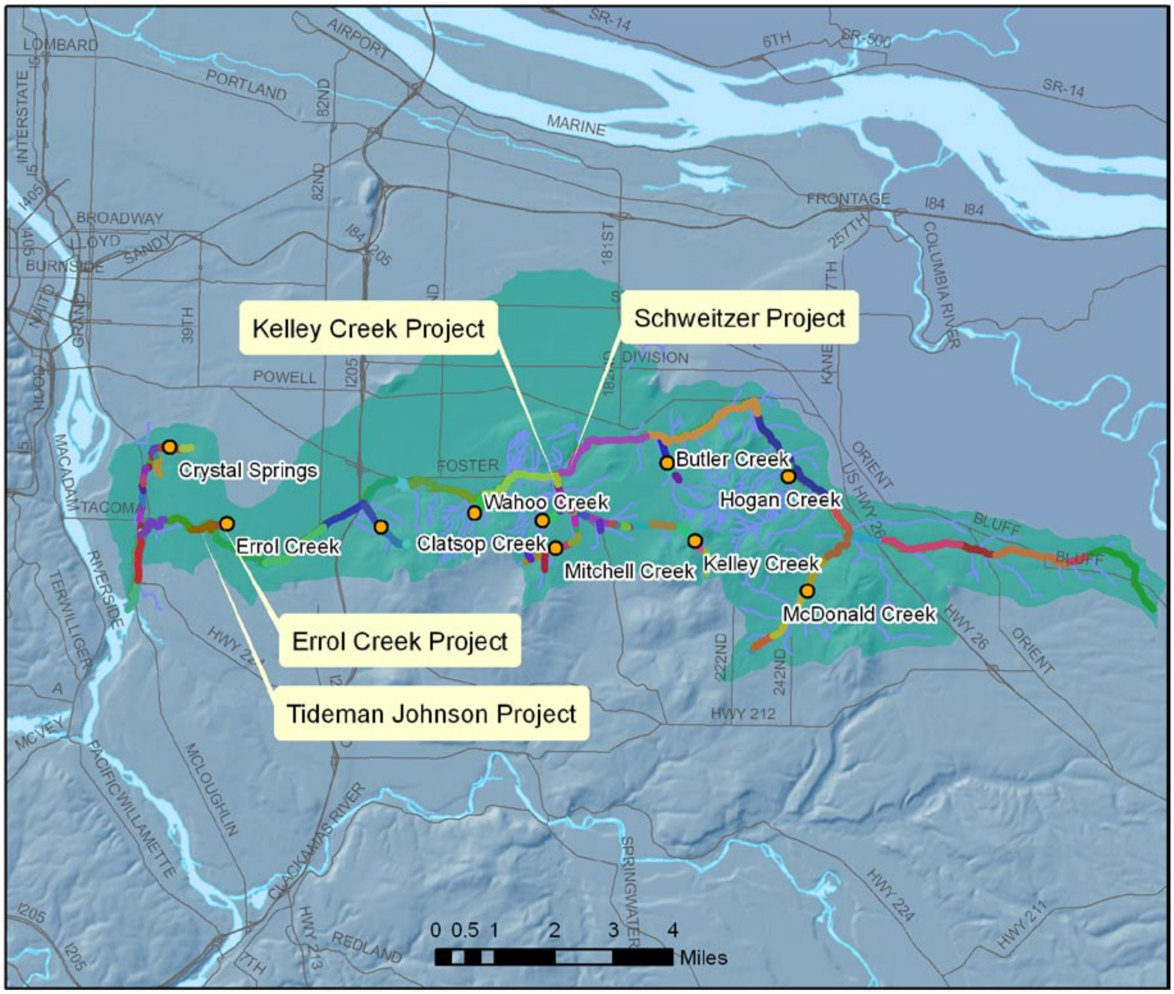
Scope of Analysis

The objective of the analysis described here was to assess the effects of five major restoration projects on the potential of Johnson Creek watershed to maintain salmonid populations. The investigation covered five restoration actions that have occurred since 2000 in the following areas of Johnson Creek (Figure 1):

- Tideman Johnson Park (stream mile 2.7)
- Errol Creek (stream mile 2.9)
- Kelley Creek (two projects) (stream mile 10.8)
- Schweitzer (stream mile 12.8)

The investigation evaluated the effects of restoration actions on three salmonid indicator species: coho, winter steelhead, and fall Chinook. These species serve as indicators of the normative condition for Johnson Creek and the status of conditions for the co-evolved normative biological community. Figure 1 shows the restoration projects in Johnston Creek watershed considered in this analysis. Reaches are denoted by thick colored lines; labeled dots show major tributaries.

Figure 1. The Johnson Creek Watershed with Stream Reaches and Restoration Projects Considered in this Analysis.



Watershed Description

The following description is based on the draft watershed characterization by the Bureau of Environmental Services (2005). The Johnson Creek watershed (54 square miles) is within the Willamette River watershed in western Oregon (Figure 1); the mouth of the creek is approximately 18 miles from the confluence of the Willamette with the Columbia River. The headwaters of Johnson Creek watershed are largely in unincorporated Clackamas and Multnomah counties and the City of Gresham, while the lower watershed is primarily within the cities of Portland (38% of the watershed) and Milwaukie. Land use is highly variable, with predominantly agricultural and forested land outside the urban growth boundary (8% of the watershed[1]) and mixed urban uses (i.e., residential, industrial, commercial, and open space) within the boundary (91% of the watershed).

The strong contrast of winter versus summer precipitation in the Pacific Northwest gives Johnson Creek a strongly seasonal hydrograph. For example, in mid-lower Johnson Creek (at the Sycamore USGS gauge), flow during winter storms is often between 100 and 300 cubic feet per second (cfs), while summer baseflow is typically less than 10 cfs (Lee and Snyder 2009). The dimensions of the watershed (i.e., long with relatively short tributaries) and impervious surfaces in urbanized portions of the watershed cause rapid fluctuations in flow during storms (Clark 1999). Several tributaries in the watershed are spring-fed (e.g., Crystal Springs and Errol Creek), and, therefore, have less variable flow throughout the year.

Water quality in Johnson Creek varies with land use and underlying geology (Sonoda and Yeakley 2007; Waite et al. 2008), but does not meet Oregon Department of Environmental Quality (ODEQ) water quality standards for bacteria, summer temperature, or compounds including DDT, PCBs, and PAHs (ODEQ 2000). Given that the Damascus area is expected to experience a ten-fold increase in population from 1994 to 2020 (Metro 2004), urbanization will be an increasingly important driver for water quality in Johnson Creek in the foreseeable future.

The Johnson Creek watershed has been dramatically altered over the years due to urbanization and agriculture. Prior to about 1900, the watershed was largely forested, including extensive forested wetlands, especially in the very low-gradient Lents area (Johnson Creek Watershed Council 2003). Johnson Creek was a low-gradient stream with a complex channel and high levels of structure provided by large amounts of downed trees and wood (McConnaha 2003). The upper watershed now has largely agricultural land uses, consisting of small farms and nursery operations. Proceeding toward the mouth, the watershed is increasingly urbanized. The most pervasive modification of the stream itself occurred in the 1930s when the Works Progress Administration (WPA) undertook a major re-engineering of the stream in an effort to control persistent flooding. Extensive sections of the stream were diverted into an artificial channel constructed with basalt armoring on the bank and large cobble on the channel floor (Photo 1). The stream was straightened and diverted from its original floodplain. Although the WPA work was not effective in controlling flooding of the stream, it did radically alter the character of the stream (McConnaha 2003). Salmon were reported in some abundance in the stream up through the mid-twentieth century despite degradation of water

[1] This includes the expansion area added to the urban growth boundary in 2002.

quality, riparian condition and other factors. During the latter part of the century and following the WPA modifications, salmon abundance declined to the present condition with minimal abundance and ESA listing of most anadromous salmonids in Johnson Creek.

Photo 1. Example of WPA Modification of Johnson Creek Stream Channel (Reach 13 off Foster Road)

Indicator Species

Our conclusions about the efficacy of restoration projects and the general condition of Johnson Creek were made relative to the needs of three native salmonid fishes: coho salmon (*Onchorhynchus kisutch*), fall Chinook salmon (*O. tshawytscha*) and winter steelhead (*O. mykiss*). These species were historically present in Johnson Creek (Folger 1998). We use these species as indicators of diverse conditions in the stream relative to its normative condition. In this light, our analysis is relevant not only to the focal fish species but also to the co-evolved biological community typical of the lower Columbia River region.

Coho, Chinook, and steelhead were historically abundant in the lower Willamette River, but have experienced significant declines including their virtual extirpation from many urban streams, including Johnson Creek (Meross 2000; Myers et al. 2006). Populations of the three indicator species do exist in the nearby Clackamas River (Figure 1). While all three species are still present in Johnson Creek (Tinus et al. 2003; Prescott 2006), they are not considered to be self-sustaining and are probably supported to a large degree by the more productive populations in the Clackamas River. All three salmonid indicator species are listed under ESA. Coho in Johnson Creek are part of the lower Columbia River coho Evolutionarily Significant Unit (ESU), which is listed as threatened. Fall Chinook in the lower Willamette River are part of the lower Columbia River Chinook ESU, which is listed as threatened. Winter steelhead are part of the Willamette River steelhead Distinct

Population Segment (DPS), which is also listed as threatened. Johnson Creek is designated critical habitat for steelhead and for Chinook in Lower Johnson up to and including Crystal Springs. Critical habitat for coho has not yet been designated.

While this analysis focuses on Johnson Creek, conditions in the lower Willamette and Columbia rivers strongly influence the performance of salmonids in Johnson Creek. For instance, habitat in the Willamette River provides rearing and migration habitat (Friesen 2005) that potentially augments habitat in Johnson Creek (McConnaha 2003). Juvenile coho also make use of the Columbia River estuary for additional growth that likely increases marine survival (smolt-to-adult return or SAR) rates (Bottom et al. 2005). Thus, it is most accurate to consider Johnson Creek as part of a continuum of freshwater habitats that extend from the headwaters, through the lower Willamette River, and into the Columbia River estuary. The abundance of fish returning to the stream is an index of normative conditions throughout that continuum.

Coho Salmon

Coho generally spawn in small, lower-gradient stream reaches and side channels during mid-autumn or early winter (Lestelle 2007). In Johnson Creek, coho likely spawn from mid-October through the end of January (Todd Alsbury, ODFW pers. comm.). Based on habitat preferences, we presumed that all reaches of Johnson Creek below barriers were potentially available to coho salmon. A small portion of male coho return to freshwater in their first ocean year (as jacks), but most coho return after 2 years in the ocean. Adults proceed upstream to spawning grounds at approximately 3 years of age and die after spawning.

Juvenile coho favor relatively slow-moving water such as pools downstream of riffles. Juvenile coho have been observed in lower mainstem reaches of Johnson Creek and in lower reaches of Crystal Springs (Tinus et al. 2003). Coho usually spend 1 year in freshwater and emigrate in the spring of their second year. In Johnson Creek and nearby streams, smolts move into the Willamette River and then into the Columbia River estuary where they may feed and rear for periods of a few days to months prior to entering the ocean (Bottom et al. 2005). Friesen et al. (2005) reported extensive use of the lower Willamette River by juvenile coho, although they moved through the area quickly, generally spending 1-2 weeks in the lower Willamette. Juvenile coho were abundant in shallow water areas where feeding and growth would occur. Once in the ocean, coho remain over the continental shelf, and are, therefore, a target of commercial and sport troll fisheries. Coho have been extensively exploited by commercial and sport fisheries with harvest rates exceeding 80% in the mid-1980s (PFMC 2001). Recent harvest rates have been considerably reduced but significant harvest continues on lower Columbia River coho including any originating from Johnson Creek.

Winter Steelhead

Native steelhead in the Willamette River are classified as winter-run. (Busby et al. 1996). Summer-run steelhead occur, as well, but these are the result of hatchery releases. Steelhead are renowned for their ability to ascend into the upper areas of streams and often spawn in higher-gradient reaches of streams (Busby et al. 1996). In the Clackamas River, winter steelhead usually spawn from January through April. However, in Johnson Creek, the spawning period would likely end earlier as a result of the warm temperatures in Johnson Creek late spring (Todd Alsbury, ODFW, personal communication). Based on habitat preferences, we presumed that all of Johnson Creek below existing natural and artificial barriers was potentially useable by steelhead.

Juvenile steelhead emerge from the gravel in spring. As juveniles, winter steelhead make use of shallower, faster-moving water than coho or Chinook. Although the distribution of juvenile steelhead in Johnson Creek is not well established, presumed steelhead[2] were observed in the Lents area when it was dewatered for construction (Prescott 2006). In spring, usually 1 to 3 years after hatching, steelhead juveniles emigrate from Johnson Creek. Friesen et al. (2005) reported that steelhead move rapidly through the lower Willamette and were usually found in deep-water areas. Steelhead continue to move rapidly downstream toward the ocean and spend little time in the Columbia River estuary (Bottom et al. 2005).

The age structure of a viable steelhead population in Johnson Creek is not known. We hypothesize that adverse habitat conditions in Johnson Creek would favor a population in which most steelhead smolt after 1 or 2 years, giving the population a younger age distribution than in the Clackamas (Alsbury personal. communication.). Steelhead usually spend 1 to 3 years in the ocean and return to freshwater to spawn; winter steelhead enter the watershed during late fall. Although most adults die after spawning, some fraction undergo multiple cycles of migration and spawning.

Fall Chinook

Fall Chinook spawn in mainstem stream and river reaches and generally favor larger river areas compared to coho and steelhead. Their natural distribution in Johnson Creek is unknown; however, it is likely that fall Chinook would favor the lower portions of the stream, especially the mainstem of Johnson Creek. In this analysis we assumed that fall Chinook were limited to the lower stream reaches below Interstate (I) 205 (Figure 1).

In the lower Columbia River, fall Chinook spawn from mid-October through the end of November. Fall Chinook in the Columbia Basin are predominantly ocean-type, meaning they spend a relatively short time in their natal areas and begin moving toward the estuary soon during their first summer (sub-yearlings). Juvenile Chinook have been observed in lower Johnson Creek, especially the Crystal Spring tributary (Tinus et al. 2003). Friesen et al. (Friesen et al. 2005) reported large numbers of sub-yearling fall Chinook in the lower Willamette River, where they favored shallow-water areas, likely indicating feeding and rearing. Fall Chinook remain in coastal waters for 2 to 4 years, where they are heavily impacted by commercial and sport fisheries. A portion of males return to freshwater as jacks in their first year. Pre-spawning adults enter the Columbia River in August and September and move rapidly to mainstem and tributary spawning areas.

Restoration Projects

Five major restoration projects were implemented by the City between 2000 and 2009 and were analyzed in this study (Table 1). These projects were undertaken for infrastructural reasons such as flood control as well as to improve instream riverine conditions for fish and wildlife. These projects resulted in significant changes to the nature of conditions in the stream. We projected the likely biological response to these changes as a means to compare and assess the contribution of the projects to restoration of native salmonids and their ecosystems.

[2] These fish were differentiated from non-anadromous rainbow trout based on size.

Table 1. Restoration Projects in Johnson Creek Considered in this Analysis

Restoration Area	Main Reach	Additional Reach(es)
Tideman Johnson	Johnson 5A	—
Errol Creek	Errol 1	Johnson 5B
Schweitzer	Johnson 14	—
Kelley Creek Restoration	Kelley 1	Johnson 14 Johnson 13
Kelley Creek Obstructions	Kelley 1	Kelley 2

Tideman Johnson Park

In 2006, the City completed a major restoration project in Tideman Johnson Park (Photo 2. Johnson Creek at Tideman Johnson Park before (top photo) and after (lower photo) Restoration

). The infrastructural purpose of the project was to protect a sewer pipe that went under the stream; down-cutting of the stream had exposed the pipe creating potential maintenance and water quality issues. As part of the effort to fix the sewer line, the City took the opportunity to enhance habitat conditions in the stream and riparian area.

Tideman Johnson Park is adjacent to the intersection of SE 37th Avenue and the Springwater Corridor in Johnson 5A Reach (Figure 1). The restoration site extends along 0.3 mile of the creek. Restoration activities included protecting and burying the exposed sewer pipe, reducing erosion of the streambank, and restoring the floodplain. Significant instream habitat enhancements occurred as part of this project, such as the addition of large wood and cobbles to increase habitat heterogeneity. The streambank was reshaped to reduce erosion, provide additional flood storage, and enhance stream-floodplain ecological connections. Plantings, large wood, and boulders were placed to additionally reduce erosion and provide a better vegetated riparian area. Finally, a boardwalk was added to minimize foot traffic in the riparian area. The majority of work was completed in 2006.

Photo 2. Johnson Creek at Tideman Johnson Park before (top photo) and after (lower photo) Restoration

Errol Creek Confluence

Errol Creek is a small tributary entering Johnson Creek just upstream of Tideman Johnson Park (Photo 3). The stream originates from springs in the Errol Heights wetland and flows about 0.3 mile to Johnson Creek. The restoration project is at the confluence of Errol Creek with Johnson Creek near SE 45th Avenue and Harney Street in Johnson 5B Reach (Figure 1). After leaving the wetland, Errol Creek flows through backyards of a small neighborhood where the stream has been landscaped and usually tightly confined within rock or cement walls. To restore the Errol Creek confluence, the City acquired properties and removed dwellings, and is restoring the stream and wetland. This restoration project addressed conditions in the lowermost 0.07 mile (385 feet) of Errol Creek (Errol 1 Reach), though the City also previously removed a culvert and restored the wetland upstream of SW 45th Avenue. Major actions of the current project include moving the stream out of its cement-lined channel into one composed of natural materials, increasing the stream length and complexity, day-lighting a portion of the creek that was in a culvert, creating a wetland designed to accommodate storm flows from Johnson Creek, placing large woody debris, and revegetating the site with native plants. The bulk of the project was completed in 2009, but final revegetation is scheduled for completion in 2010. For the purposes of this status and trends analysis, we have proceeded as though it was complete.

Despite restoration, Errol Creek remains quite small. We assumed that the stream is unlikely to provide significant salmonid spawning habitat; however, the wetland and stream will provide off-channel habitat for salmonids that use this portion of Johnson Creek as juveniles and pre-spawning adults.

Photo 3. Mouth of Errol Creek before and after Restoration

Schweitzer

Also referred to as "Alsop-Brownwood," the Schweitzer project is the City's most ambitious stream restoration effort to date. The site is in the middle portion of Johnson Creek—Reach 14—near SE 159th Drive and Foster Road (Figure 1). The infrastructural purpose of the restoration was to provide overbank flood storage and to moderate the frequent flooding that occurs in this section of the stream. To accomplish this, the City attempted to restore much of the natural riverine function of the section that had been removed by extensive WPA alteration of the stream channel. Prior to restoration, the Schweitzer section of Johnson Creek was an example of the WPA's flood-control efforts (Photo 4). The WPA work moved the stream out of its original channel into an artificial channel lined with basalt blocks. The stream followed the margin of a field and had little connection to its floodplain and very limited capacity for storing storm flows.

The Schweitzer project involved excavating a new channel for Johnson Creek and crafting a floodplain to provide over-bank flood storage. The elevation of the floodplain was reduced by about 12 feet, while a new channel was constructed that was intended to mimic the sinuosity and channel complexity of the original, natural stream channel. The lowered floodplain, backwaters and other features provide flood storage. The intent is also to allow Johnson Creek to deposit silt in the floodplain, rather than in the main channel, during periods of high flow. The riverine character of the stream was enhanced by adding woody debris structures, cobbles and gravel, and riparian tree plantings. Once the riparian plants are tall enough to provide shade, they are expected to moderate stream temperatures; currently, they are too small to have an effect on instream conditions. The project was completed in 2007.

Photo 4. Site of the Schweitzer Restoration Project before (upper photo) and after (lower photo) Restoration

Kelley Creek Confluence

Kelley Creek is the largest tributary to Johnson Creek (Figure 1, Photo 5), and is located immediately downstream (west) of the Schweitzer site. The lower portion of the stream was channelized and armored, probably as a result of the WPA activities. In 2004, the City completed an extensive restoration project in the lowermost 0.09 mile (480 feet) of the stream up to 159th Drive (Figure 1). Actions included adding sinuosity to the stream channel and adding large woody debris and cobbles to improve habitat heterogeneity. The angle of the stream banks was reduced to allow the stream to connect with the floodplain. The floodplain itself was sculpted and extensively planted with native vegetation. Off-channel habitat was added as backwater spur channels and wetlands adjacent to the stream. Two of the three backwater spur channels are on Johnson Creek itself (in reaches 13 and 14).

Photo 5. Confluence of Kelley Creek with Johnson Creek before (upper photo) and after (lower photo) Restoration

Kelley Creek Obstructions

Above 159th Avenue, Kelley Creek was extensively altered by stone works and by passage under Foster Road. The section from 159th Avenue to Foster Road had constructed waterfalls and a large pond (Lakeside Gardens) (Figure 1). The stream passed under Foster Road through two box culverts that greatly restricted anadromous fish access to the Kelley 2 Reach (Photo 6). Kelly 2 Reach, above Foster Road, contains some of the best natural stream habitat in Kelley Creek. The National Marine Fisheries Service required the City to correct the passage problems under Foster Road when the road above it was reconfigured. In response, the City constructed a large arch culvert that should provide complete connectivity of Kelley 1 and Kelley 2 reaches (0.75 miles). At the same time, the City created notches in the constructed waterfall steps that also restricted passage below Foster Road (Photo 7).

Photo 6. Box Culverts on Kelley Creek at Foster Road prior to Restoration

Photo 7. Step Structures on Kelley Creek prior to Restoration

Analytical Approach

In this analysis, we compared the habitat potential of Johnson Creek in 200 to that in 2009 for three indicator fish species: coho salmon, fall Chinook salmon, and winter steelhead. "Habitat potential" is the capability of the environment in a given condition to support species of interest. It is based on both the genetically determined habitat needs and preferences of the species as well as the quantity and quality of habitat available to the species in a particular environment over the course of its life history. Because each of the indicator species has its own habitat requirements and preferences, they view the environment in Johnson Creek differently (Mobrand et al. 1997), requiring species-specific assessments of the stream and of the restoration projects. The multi-species approach used in this analysis provides a broader, community-based assessment of the stream and the restoration projects.

Habitat potential is measured by the expected species performance under the environmental condition. An example performance measure is the theoretical adult abundance in the watershed when the population is in equilibrium with the environment. In this analysis, the restoration projects were compared in terms of the change in expected population abundance after restoration (in 2009) compared to the conditions prior to restoration (in 2000). Actual abundance of fish observed in any year may differ considerably from the habitat potential, as actual values reflect natural environmental variation and the effect of non-habitat factors (e.g., harvest and ocean survival conditions, incomplete colonization of newly available habitat). Several metrics of habitat potential in addition to abundance are available from this analysis, including biological capacity, productivity, and life history diversity. These metrics are consistent with measures of a Viable Salmon Population used to assess salmonid populations under ESA (McElhany et al. 2000).

The starting point for the analysis was conditions in Johnson Creek in 1999. In that year, the City commissioned the Oregon Department of Fish and Wildlife (ODFW) to conduct a detailed survey of habitat conditions in Johnson Creek and its tributaries (ODFW 1999; 2000, subsequently referred to as the 2000 condition). That assessment was the basis for development of a detailed species-habitat model for Johnson Creek (McConnaha 2003) that was used by the City to evaluate conditions in Johnson Creek using coho salmon as the indicator species. The analysis provided a diagnosis of conditions in the stream and a roadmap for its restoration and management (McConnaha 2003).

Following completion of the 2000 Johnson Creek model and the stream assessment, the City undertook the five restoration projects in Table 1. To analyze their impact, we modified the data from the 2000 ODFW survey to reflect changed conditions resulting from the restoration projects that exist in 2009 (details of the methodology are provided below). Conditions outside the immediate area of the restoration project were assumed to be the same as they were in the 2000 survey.

We then calculated the watershed scale biological performance for the three indicator species under several sets of environmental conditions using the Ecosystem Diagnosis and Treatment (EDT) model (Blair et al. 2008). We parameterized the model to reflect conditions in the stream for the

2000 and 2009 scenarios (without and with restoration) as well as for historic reference conditions in terms of physical and biological stream attributes (Appendix A). Habitat assumptions associated with each of the restoration actions are shown in Appendix B. While the primary analysis was of the five restoration projects together, we also analyzed the changes in biological performance that would have occurred if each project had been built but the others had not. This analysis was also at the watershed scale, and focused on changes in adult abundance for the three indicator species.

Due to the large size of the watershed compared to the restoration sites, it is useful to evaluate the impacts of the restoration actions at the reach scale, in addition to their impacts at the watershed scale, To this end, we evaluated the changes that the five restoration projects, taken together, had with respect to biological performance at the reach scale. We used EDT to measure the limiting factors in the four main reaches in which restoration occurred (Table 1). We also analyzed the changes in restoration and protection value for all reaches within the watershed.

Johnson Creek Habitat Model

Using the approach for EDT status and trends analysis described above, we developed a salmonid habitat model for Johnson Creek (Lichatowich et al. 1995; Blair et al. 2008). We used the model to compared biological performance of the indicator species under three conditions:

1. Conditions in 2000 as reported by ODFW (ODFW 1999, 2000)
2. Conditions in 2009 representing environmental changes due to restoration projects
3. A template or reference condition

The Johnson Creek EDT model consists of two major components. The first component is the environmental description. This is a reach-level depiction of conditions based on the ODFW surveys and additional published information. The second component describes the biology of the indicator species. This includes life history information (e.g., time spent in Johnson Creek, maturation schedules, and fecundity) and the definitions of fish populations (e.g., spawning periods and spawning reaches). Population structure and assumptions in the Johnson Creek EDT model have been described in Schwartz and Caplan (2009). The biological depiction of the indicator species also includes a library of species-habitat relationships, or the relationship between survival and capacity for life stages of each species (e.g., eggs, fry, smolts and adults) and environmental conditions (e.g., temperature, sediment, structure and flow). The combination of the environmental description and the biological information is an evaluation of the environmental condition “through the eyes of salmon” (Mobrand et al. 1997).

Template Condition

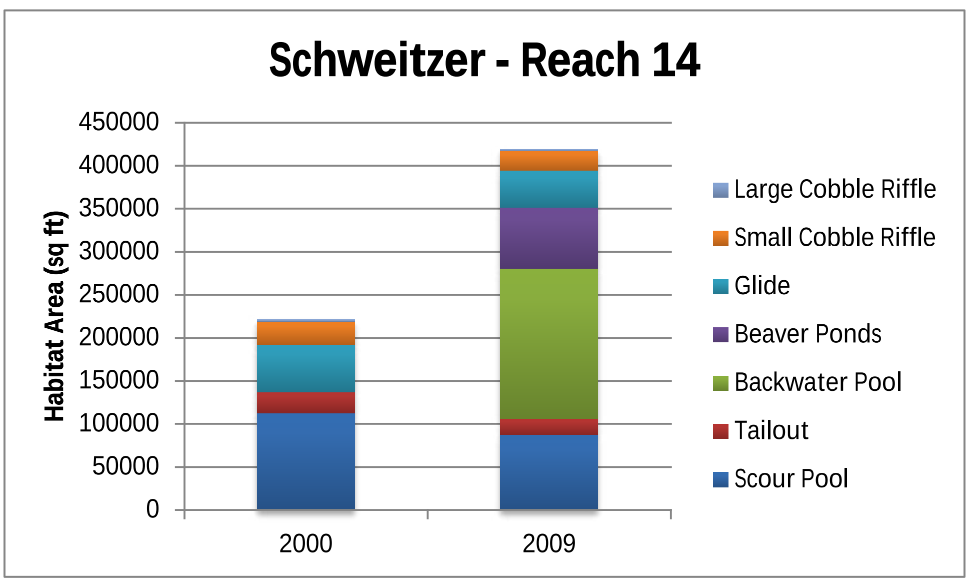
The template condition is used as a point of reference to understand how urbanization has altered conditions in Johnson Creek and biological performance of the indicator species. Comparing species performance under the template condition to that under recent conditions provides insights into the extent of urbanization and provides a basis for defining habitat. The template condition applies to reaches within the Johnson Creek watershed as well as to the lower Willamette River. The lower Columbia River is described by a single set of conditions in all model runs.

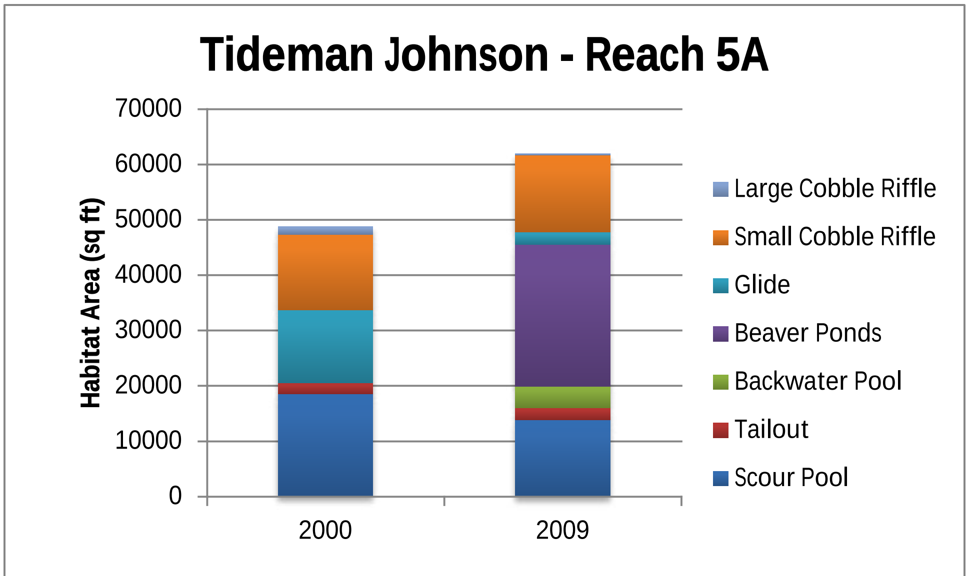
Template conditions describe the state of the stream without human alterations and are largely hypothetical, but inferred from a variety of information sources. These were described by McConnaha (2003); only the most influential attributes are explained here. Reach lengths were assumed to be 10-50% longer in the template condition than in 2000 (see below), given the extensive straightening that Johnson Creek has experienced (Metro 2000). Widths were also assumed to be 10-50% greater than in 2000, depending on how confined the channel would have been by natural features. Habitat composition was based largely on gradient, derived from relationships in unmanaged streams in western Washington (Peterson et al. 1992). Stream temperatures were assumed to be cooler than they are currently, though varying geographically as they do currently. Many other attributes are zero by definition when there is no anthropogenic influence in the stream (e.g., nutrient enrichment, fish species introductions), so ratings (of zero) could be applied without specific historical information.

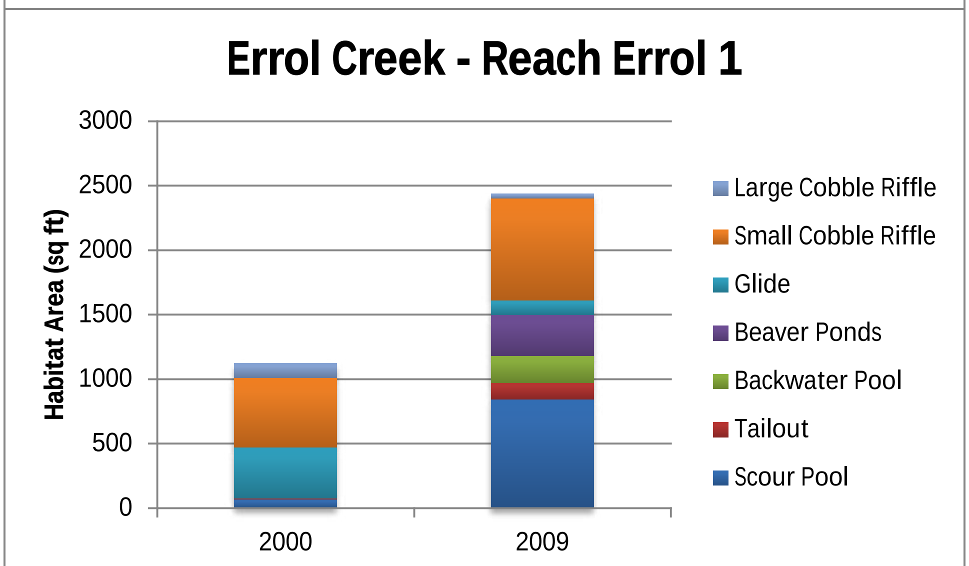
Conditions in 2000

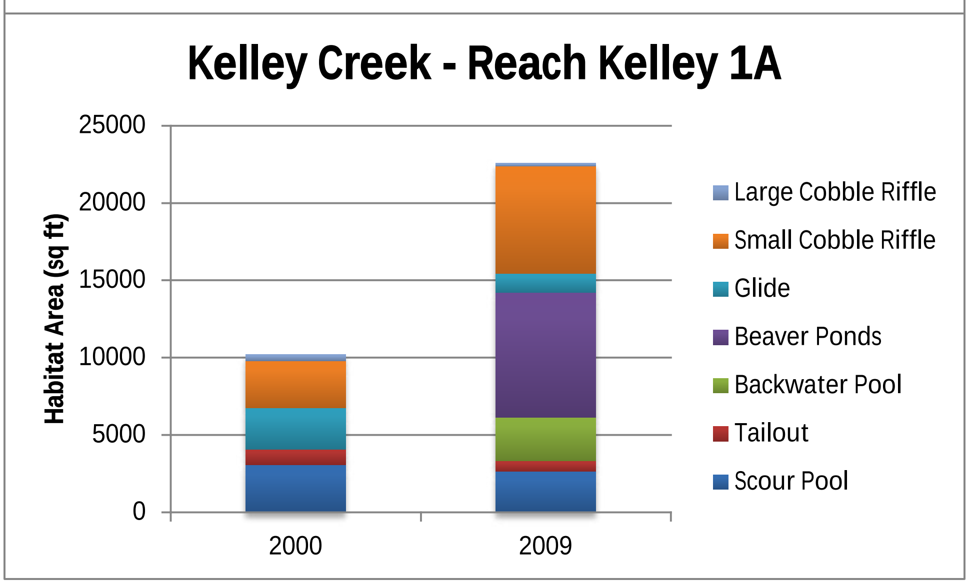
The 2000 Johnson Creek EDT model was developed by McConnaha (2003) based on extensive instream surveys performed by ODFW (1999; 2000, Figure 2). These surveys used standard Oregon habitat assessment methods (Moore et al. 1997). Information from the ODFW survey was augmented by data from the City, U.S. Geological Survey (Edwards 1994), and other management agencies. A number of agency reports and studies from the scientific literature were also incorporated. Examples include studies of the biological communities (Pan et al. 2001), water chemistry (Sonoda et al. 2001), effects of urbanization on stream flow (Clark 1999), and obstructions to fish passage (McDermott et al. 1999).

Figure 2. Average Habitat Area and Composition in the Primary Reaches where Restoration Occurred. Note that the vertical scale differs in each graph.




Tideman Johnson - Reach 5A
Habitat Area (sq ft)
70000
60000
50000
40000
30000
20000
10000
0
2000
2009
Large Cobble Riffle
Small Cobble Riffle
Glide
Beaver Ponds
Backwater Pool
Tailout
Scour Pool


Errol Creek - Reach Errol 1
Habitat Area (sq ft)
3000
2500
2000
1500
1000
500
0
2000
2009
Large Cobble Riffle
Small Cobble Riffle
Glide
Beaver Ponds
Backwater Pool
Tailout
Scour Pool


Kelley Creek - Reach Kelley 1A
Habitat Area (sq ft)
25000
20000
15000
10000
5000
0
2000
2009
Large Cobble Riffle
Small Cobble Riffle
Glide
Beaver Ponds
Backwater Pool
Tailout
Scour Pool

Conditions in 2009

The 2009 Johnson Creek EDT model began with the data in the 2000 model but modified conditions to represent the restoration projects completed since 2000 (Appendix B). An intensive data collection effort was made by ICF and the City to quantify the changes resulting from restoration in the prior decade. Data collection focused on the parameters changed most significantly by the restoration activities:

- Channel morphometry (length and width)
- Habitat composition (e.g., pools, riffles, glides)
- Large woody debris
- Channel confinement (artificial confinement or hydro-modifications)
- Riparian function

Measurements of channel morphometry relied primarily on CAD designs of the restoration sites, though data from field surveys and aerial photographs were used to supplement and validate CAD-derived data. Widths and lengths during the months of minimal and maximal flow (August and January) were measured for the main channel at each site and for all backwater channels. January widths were based on ordinary high water level, top of bank, or a contour line corresponding to a 9- to 12-month flood event, depending on the data available. Wetted surface area was calculated from these data for high- and low-flow months, as well as the average. Elevations at the upstream and downstream ends of main channels were also measured and used with length measurements to quantify stream gradient across the restoration site.

The habitat composition at restoration sites was measured in the field (with the exception of backwater, described below) by City personnel in July and August of 2009. Because ODFW categorizations had been used when the data were collected (Moore et al. 1997), we aggregated habitat units (by summing their areas) to determine the composition as per the EDT categorization: primary pools, pool tailouts, backwater pools, beaver ponds, glides, small cobble riffles, and large cobble riffles (Figure X, Lestelle 2004). Because the Errol Creek restoration is not completed, we assumed that the habitat composition within the stream would be similar to that of Tideman Johnson when complete, but with a smaller fraction of beaver ponds. The assignment of wetland habitat area at the juncture of Errol Creek and Johnson Creek was split between Errol Creek and Johnson 5B Reach. We included the area of backwater channels into the area of the main channel by adjusting the width upwards but retaining the true channel length. Although backwater habitat often occurred as spur channels off of the main channel, EDT ignores the arrangement of channels and ultimately uses main channel area and length in its computations. We were therefore able to account for the quantity of backwater channels and their functional contribution to the stream ecosystem, without altering the geometry of the reaches.

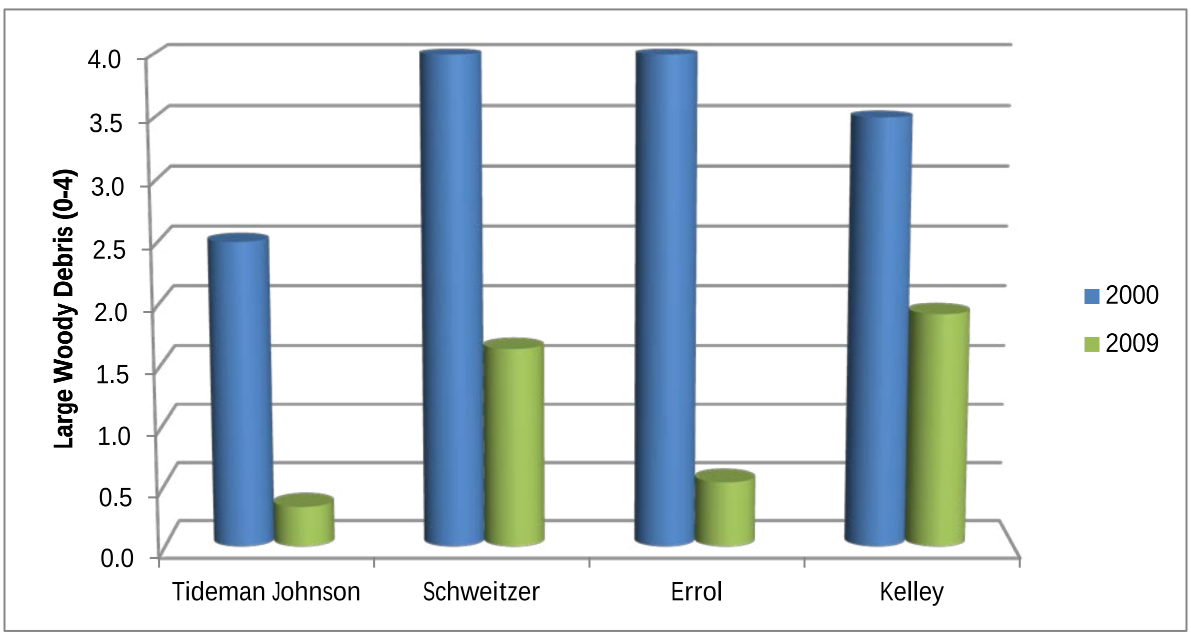
Ratings for the amount of large wood that had been placed in restoration sites were also based on CAD designs. We recorded counts of wood pieces, making the assumption that pieces placed would meet the minimum requirements to be considered large wood by EDT (>0.1m in diameter and 2m in length; Lestelle 2004). Counts were converted to EDT ratings as per the EDT guidelines, using the number of pieces per unit length of stream in which they occur (Figure 3). Data from instream surveys were used to verify that CAD-derived data accurately reflected true conditions.

Artificial confinement (hydro-modifications) was rated by the presence and extent of WPA armoring or bridges (City of Portland 2007). Riparian function was rated by expert opinion, mainly based on interpretation of aerial photographs and site visits. High values for riparian function were indicated by mature riparian vegetation and connectedness during overbank flows, while low values were indicated by the lack of these indicators (Lestelle 2004). Immature riparian plantings (e.g., at Schweitzer) were rated according to their current state, although they would be expected to have greater values in the future. Values for Errol Creek were estimated for the site at the time of completion.

We updated the estimate of fish passage likelihood for the two obstructions on Kelley Creek that the City improved. The Foster Road crossing was a major obstruction for coho and steelhead in the 2000 model, especially during lower-flow periods (Photo 6). As a result of restoration, the Foster Road crossing was rated to pose no impediment to adult or juvenile salmonid migration in the 2009 model. The waterfall steps were rated to allow passage to a higher fraction of upstream moving fish during all months. However, these structures could still pose a partial barrier (Photo 7), particularly during low-flow months, and were rated accordingly. These actions created a continuous 0.75-mile habitat corridor from Johnson Creek through Kelley 2.

Because restoration sites were smaller than the reach units used in the model, attribute ratings for restoration sites in the 2009 model were calculated as the weighted average of ratings within each restoration site and the value for the rest of the reach (taken from the 2000 dataset). Weights were the average wetted area of the restoration site and the remainder of the reach.

Figure 3. Rating of Large Woody Debris Before and After Restoration. Values Closer to Zero Represent More Pieces of Wood Per Unit Stream Length.



Watershed Scale Analysis

Restoration Effectiveness

Restoration efforts initiated by the City between 2000 and 2009 significantly increased the habitat potential of the Johnson Creek watershed as a whole to support coho, fall Chinook and winter steelhead (Figure 4). We estimate that the five projects in Table 1 approximately doubled the habitat potential of the watershed for coho relative to the 2000 condition, and increased it by 20% for winter steelhead and 14% for fall Chinook (Table 2).

Figure 4. Potential Adult Salmonid Abundance of the Johnson Creek Watershed in 2000 and 2009

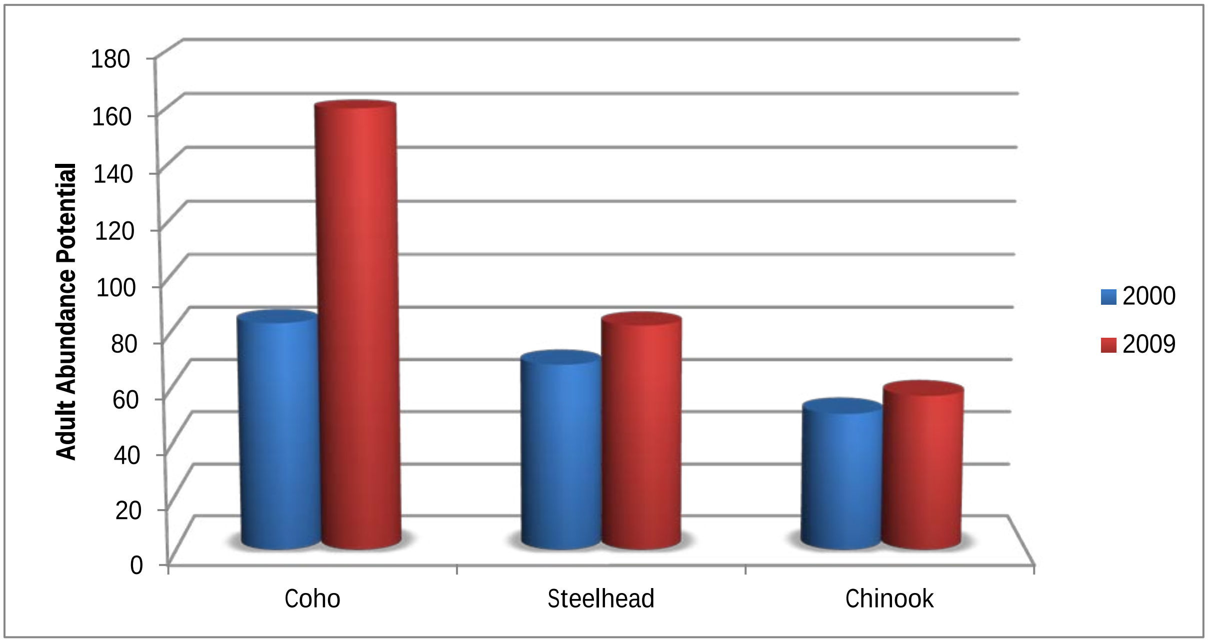


Table 2. Watershed Scale Results of Habitat Potential Assessment under Three Conditions for the Johnson Creek Watershed (Units are Adult Abundance)

Evaluation	Coho	Steelhead	Chinook
Template (Johnson and Willamette)	5,076	1,073	1,521
2000 (without restoration projects)	83	68	50
2009 (with restoration projects)	160	82	57
Gain from 2000 to 2009	77	14	7
Gain as percent of 2000	92%	20%	14%
2009 as percent of template	3.2%	7.7%	3.7%

The projects clearly provided habitat features that favored coho over the other species, most notably the backwaters added to the stream in four projects and the wetland added in the Errol Creek project. These types of habitats are heavily favored by juvenile coho for summer rearing and overwintering refugia (Bustard and Narver 1975b; Nickelson et al. 1992), but were very rare in Johnson Creek prior to the restoration actions. Steelhead, on the other hand, are less drawn to wetland and backwater habitats, but instead favor riffles during summer and take cover under cobble or wood during winter (Bustard and Narver 1975a). Fall Chinook were assumed to only penetrate as far as I-205 or about half the mainstem channel length, which corresponds to the uppermost observation in a recent survey by ODFW. As a result, they only benefited from the Tideman Johnson and Errol Creek restoration projects. Juveniles of ocean-type fall Chinook spend relatively little time in Johnson Creek compared to coho and steelhead, and will therefore always experience less benefit from restoration projects.

Despite the improvements in Johnson Creek, conditions in the Johnson Creek watershed as a whole are still greatly constrained relative to those presumed under the template condition (Table 2). The coho potential of the improved habitat in 2009 is only 3.2% of that estimated for the template condition. Current potential for the other species is slightly better: 7.7% for steelhead and 3.7% for fall Chinook. The fact that Johnson Creek has a relatively small fraction of the habitat potential for all species in 2009 as compared to reference conditions should be considered with respect to two factors. First, the total number of stream miles restored (0.98 mile, which occurred in reaches totaling 4.46 miles) is small relative to the size of the watershed (38.5 miles in Johnson Creek). Second, the reference condition not only considers Johnson Creek as being at historical conditions, but also the lower Willamette (an additional 18 miles of habitat). The differences in habitat potential among species are the result of differences in habitat preferences, discussed above. Based on historical accounts and the general topography and character of the stream, the template condition was assumed to consist of expansive wetlands, complex channel form, and ample structure. As discussed above, these types of conditions are generally favored by coho. At the same time, these are the types of conditions that have been removed from Johnson Creek and the lower Willamette River as a result of urbanization over the last 150 years (McConnaha 2003). Wetlands have been filled, large wood has been systematically removed, and the Johnson Creek mainstem has been simplified to a single, heavily armored channel by the WPA action and urbanization.

Results by Project

The analytical design allowed us to examine the effect of each restoration action independently and to compare the effectiveness of the City's actions among species at the watershed scale. Although differences in the ecology of the species make it impossible to say that any one action was "best," we identified significant differences in effectiveness among projects and in each project's effects on the indicator species (Table 3). Examining restoration projects independently also allowed us to identify synergisms in effectiveness that occurred with five restoration efforts taking place in the same system. These synergisms arise, for example, when actions affect parts of the stream used during different life stages, or when an action improves access to habitat. The magnitude of these synergisms can be inferred from differences in the effectiveness of all projects taken together (described previously) versus the total effectiveness of all restoration projects taken individually (described subsequently).

Project Effectiveness

The Schweitzer project was by far the most ambitious restoration action undertaken by the City. The project had the greatest effect of any of the projects on overall salmonid abundance primarily in regard to its effectiveness for increasing the habitat potential for coho (Figure 5). However, the project had a relatively small value for steelhead and no value for fall Chinook because it was above the furthest extent of their distribution in Johnson Creek. The effect of riparian plantings maturing through time will yield a higher gain in habitat potential at the Schweitzer site in the future, given the immature state of plantings in 2009. Restoration of lower Kelley Creek also primarily benefited coho but also provided significant benefits for steelhead. Again, the project had no value for fall Chinook (Figure 5). Fish production in Kelley Creek also benefited from improvements in passage, primarily at Foster Road. The benefit of increasing passage at Foster Road and the Kelley step structures is primarily due to improved access into relative good habitat in the Kelley 2 Reach. Errol Creek restoration benefited coho and fall Chinook but provided no benefit for winter steelhead (Figure 5). Finally, the restoration at Tideman Johnson Park provided the greatest benefit for fall Chinook, followed by winter steelhead, with relatively smaller benefits for coho (Figure 5).

The variation in species benefits among projects reflects the assumed differences in distribution of the three indicator species within Johnson Creek, environmental characteristics provided by the restoration projects, and habitat preferences. Based on typical fish behavior, we assumed that fall Chinook salmon would not penetrate the entire length of Johnson Creek, but would remain confined to stream reaches below I-205 or about halfway up the length of the Johnson Creek mainstem (Figure 1). For this reason, the Schweitzer and Kelley Creek projects provided no benefit for fall Chinook. On the other hand, coho and steelhead were assumed to move throughout the accessible portions of Johnson Creek and thereby encounter the conditions at Schweitzer and Kelley Creek.

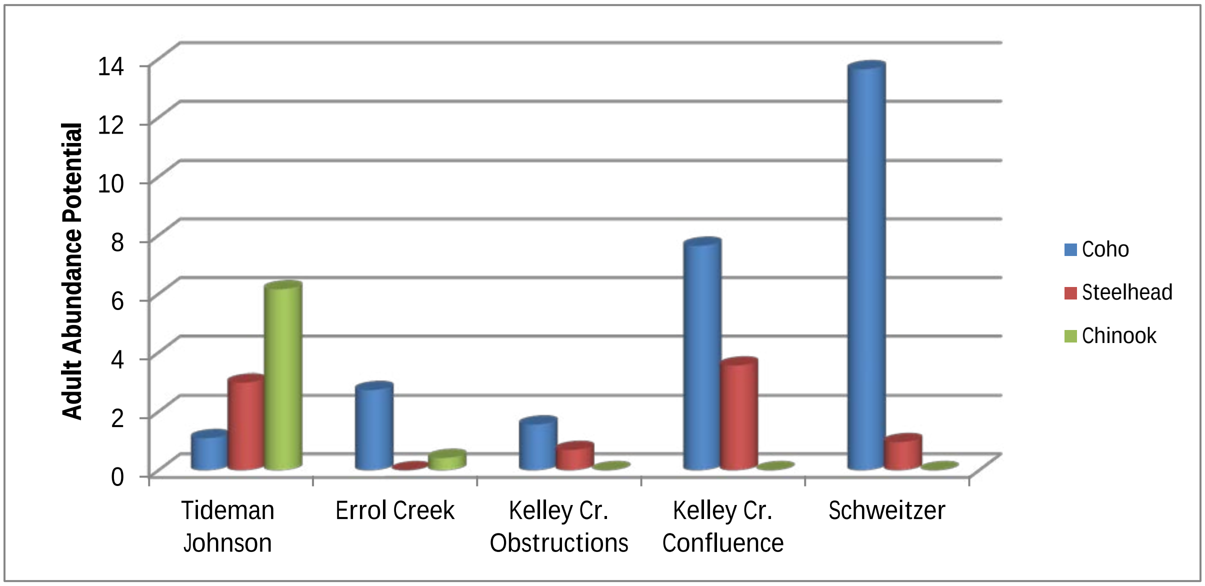
The five restoration projects provided different types of habitat features that resulted in differences in species response (Table 3). The Schweitzer and Kelley Creek projects significantly increased the amount of backwater, side-channel, and wetland habitat in Johnson Creek. These are key habitats for juvenile coho during the summer and winter periods, but are not key habitats for winter steelhead. For this reason, the addition of these types of habitat clearly benefited coho over winter steelhead. The Errol Creek restoration also provided wetland and off-channel habitats for Johnson 5B Reach, although in much smaller amounts than the Schweitzer and Kelley Creek projects. The addition of these habitat types in Reach 5B increased habitat potential for fall Chinook as well as coho, reflecting the value of these habitats for sub-yearling fall Chinook and juvenile coho.

The Tideman Johnson restoration primarily benefited fall Chinook and winter steelhead with lesser benefits for coho. This project focused on restoration of channel features associated with burial and protection of the sewer pipe. Large wood and structural elements were added to the stream channel as well. However, the project provided less off-channel and secondary channel features compared to the Schweitzer or Kelley Creek projects. The mainstem habitat characteristics provided in Tideman Johnson (Reach 5A) provided summer and winter habitat for winter steelhead and spawning habitat for fall Chinook.

Table 3. Watershed Scale Results of Habitat Potential Assessment for Individual Restoration Projects in the Johnson Creek Watershed (Units are Adult Abundance)

Evaluation	Coho	Steelhead	Chinook
Gain from Tideman Johnson	1	3	6
Gain from Errol Creek	3	0	1
Gain from Kelley Creek Restoration	8	4	0
Gain from Kelley Creek Obstructions	2	1	0
Gain from Schweitzer	14	1	0
Total of individual project gains	28	9	7

Figure 5. Changes in Adult Fish Abundance Potential from Individual Restoration Projects



Project Synergisms

The project results discussed above reflect the analysis of each project in isolation. In other words, changes in abundance (Figure 5) are the result of changing conditions appropriate to each restoration project individually while holding all other conditions constant (Table 3). When considered individually, the restoration projects provide relatively modest gains in salmonid performance. The sum of benefits across all projects considered individually was 28 coho, 9 winter steelhead, and 7 fall Chinook added to the 2000 habitat potential for each species (Table 3). The greatest benefit by this calculation was for coho from the Schweitzer project. Even when considered in isolation, it increased coho of Johnson Creek by 14 adult fish for a 16% increase in habitat potential relative to the 2000 habitat condition.

When the projects were considered in aggregate, as happens in reality and was described in the prior section, benefits were much greater than even the sum of benefits of projects considered individually. As stated above, the five restoration projects taken together increased the watershed-scale habitat potential by 77 coho, 14 winter steelhead, and 7 fall Chinook. The difference in the total abundance when considering all projects together versus summing the abundance gain under projects as individual actions, is a measure of the synergisms that arise from performing multiple actions. Previous work in Tryon Creek similarly demonstrated that projects act synergistically (ICF

Jones & Stokes 2008). Synergisms did not affect fall Chinook measurably, because almost all adult potential was a result of the Tideman Johnson restoration. Coho benefitted most greatly from synergistic effects, with adult habitat potential increasing by 275% (28 to 77), while winter steelhead experienced a 155% lift (9 to 14). Thus, consideration of projects in isolation—as they might be in a City budgeting or planning exercise—can lead to an incomplete assessment of the benefits of restoration projects.

Multispecies Diagnosis

While the number of adult salmonids that a watershed can support is an easy to interpret metric of the watershed's state, a more complete "diagnosis" can be made by assessing the degree to which individual stream attributes limit salmonid survival through their life cycle. We describe such a diagnosis here, with a similar diagnosis for the reaches in which restoration occurred provided in Appendix C. Figure 6 shows a summary of the limitation stream attributes have on each of the three indicator species for Johnson Creek in 2009. For each species, the total limitation across all attributes is shown as a ranking for each life stage. In addition, the degree of limitation by each of the 18 attributes individually is calculated as the difference between 2009 conditions and template conditions (we alternately term this metric "survival deficit"). The specific equations and the range of values for key habitat differs from the other 17 survival attributes, and is therefore symbolized differently. Blanks appear where there is no survival deficit, or where a life stage does not pertain to a species (e.g., fall Chinook do not have 1+ age life stages). Survival attributes are composites of the environmental attributes, aggregated to reflect the influence of the environmental conditions on salmonid survival (Appendix A).

Under 2009 conditions, several attributes stand out as predominantly limiting for multiple life stages of all three species (Figure 6). The structural diversity of habitat, the availability of key habitat, and chemicals are among the greatest ongoing issues in Johnson Creek. There are additional and sizable survival deficits for incubating eggs of all species from excess suspended sediment and degraded channel stability. Predation, issues related to flow (such as flashiness), and limited food affect colonizing fry. Coho and fall Chinook, which have similar spawning periods, experience the effects of temperature, competition, and pathogens (among others) as 0-age rearing juveniles, when winter steelhead do not. As one would expect, obstructions are most limiting to in-migrating adults.

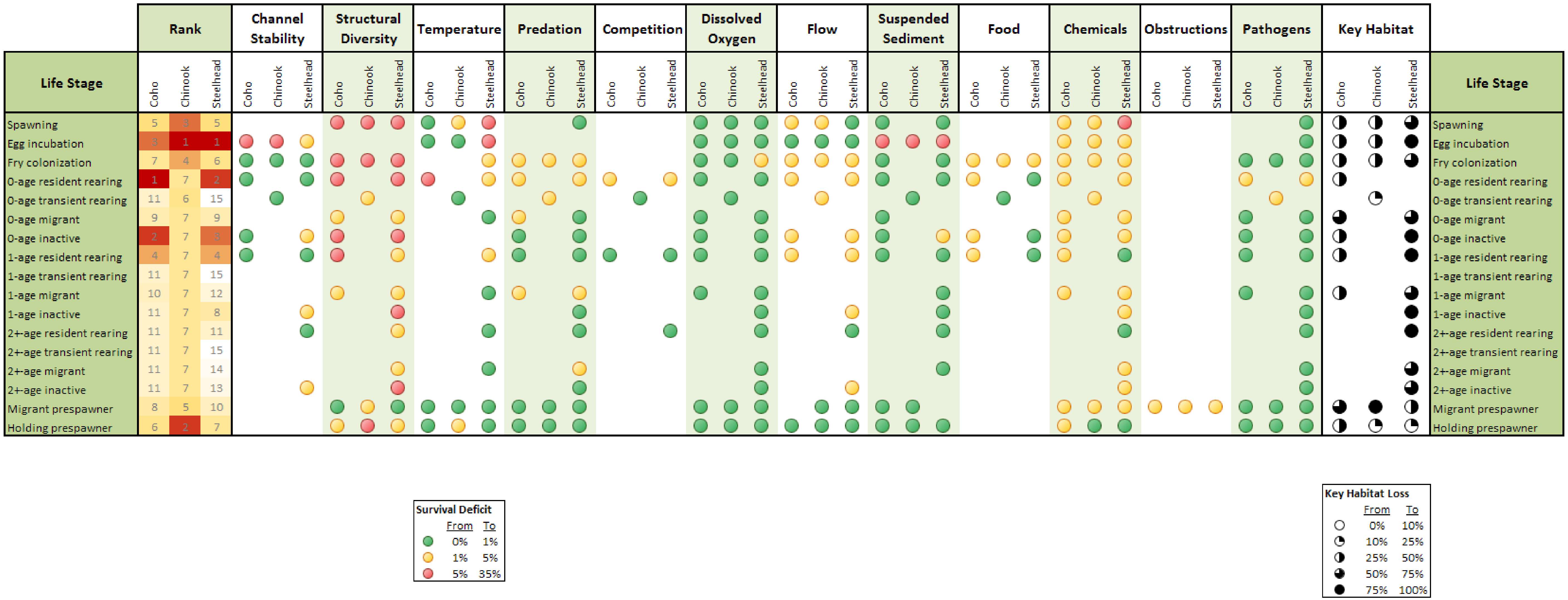


Figure 6. Limitation of Salmonid Life Stages by Survival-Related Attributes in Johnson Creek in 2009. Overall Rankings are Shown at Left, and Individual Survival Deficits are Shown as Dots or Pies.

Reach Scale Analysis

We performed two sets of analyses at the reach scale, to meet two related objectives:

(1) Evaluate the effects of restoration actions in the specific reaches in which they took place. Although the five restoration projects performed by the City between 2000 and 2009 had measureable watershed scale effects on the habitat potential of Johnson Creek, the projects only covered about 1 mile of the 38 river miles within the watershed. We evaluated the reach scale effects of the projects to better assess the local implications of the restoration actions. Although restoration projects were smaller than reaches—project sites totaled 1 river mile, while the four primary reaches totaled 2.8 river miles—the effects of restoration are significantly less “diluted” by conditions in the remainder of the watershed in this analysis.

(2) Evaluate the potential importance of each reach to inform future watershed management. Conditions in a given reach may have a greater or lesser influence on salmonid populations, due to factors like their location within the watershed, size, current condition, and potential condition if restored or degraded. We quantified the restoration and protection value of each reach (specific definitions are below) in 2009 to meet this objective, and compared the 2000 and 2009 values to explore how the City’s actions in the past decade have influenced the values. Restoration and protection information can be used to support prioritizing future actions, in that they rank reaches for their potential to support salmonids under alternative environmental conditions.

Reach Scale Effects

The straightforward metric used at the watershed scale, adult abundance potential, does not apply at the reach scale. In evaluating the reach scale effects of restoration, we therefore used two performance metrics that can be evaluated at the reach scale. These are productivity and capacity, and they describe the quality and quantity of habitat as experienced by a given indicator species. The productivity of a reach, as used here, is the number of individuals at a given life stage that could be produced per individual of the prior life stage, given the characteristics of the habitat. The capacity of a reach, as used here, is the maximum number of salmonid individuals of a given life stage a reach could support if habitat quality was not limiting. Note that capacity is greatly dependent on the size of the reach, and that that productivity is partially dependent on capacity.

We calculated the change in both capacity and productivity for each salmonid life stage in each of the primary reaches that underwent restoration. For ease of interpretation, we present the magnitude of relative change, specifically the change for a specific life stage in a specific reach as a percentage of the total change over all life stages in all reaches. Absolute capacity and productivity units are not as easily comparable among life stages.

Because salmonids have different habitat needs throughout their development, the benefits estimated in this analysis vary considerably with life stage. Species-specific differences to the environmental changes are also notable, though there are strong similarities among the salmonids considered here, particularly when the timing of life stages is aligned for the species (e.g., spawning and early development for coho and fall Chinook). The effects of each project/reach on productivity and capacity by species is highly consistent with the watershed-scale analysis; we therefore do not discuss those implications here.

Changes productivity and capacity often occurred together (Figure 7). While productivity is partly dependent on capacity, the degree of correspondence here suggests that the City's actions were sufficiently multi-faceted to improve both metrics significantly. In other words, the actions not only created more habitat, they raised the quality habitat compared to the habitat present in the corresponding reaches in 2000. The greatest benefits of restoration for coho and winter steelhead, both in terms of capacity and productivity, was for overwintering juveniles (e.g., 0-age inactive). Capacity, and to a lesser extent productivity, improved for juvenile rearing, particularly for the first summer (0-age resident rearing).

It is important to reiterate that the effects of the restoration actions documented in this analysis do not represent their full effects. It will take a number of years for riparian vegetation to become mature, but once it does there will likely be measurable effects on both riparian area and temperature (from shading).

Restoration & Protection Value

We quantified the value of restoring or protecting individual sections of Johnson Creek for coho, winter steelhead, and fall Chinook. The sections we evaluated were individual reaches for the mainstem of Johnson Creek and in the Willamette River, groups of reaches for the remainder of the watershed (e.g., upper Kelley Creek or Butler Creek). The scale used to quantify restoration and protection value was the change in predicted abundance at the watershed scale when environmental attributes of each reach or section had template or degraded levels substituted in for current levels (which was either 2000 or 2009). All remaining reaches/sections were held at current levels in making this evaluation. Thus, these metrics quantify the importance of individual reaches, though they measure watershed scale abundance potential. The metric for restoration value was the change in abundance with environmental conditions restored completely in individual reaches, while the metric for protection value was the change in abundance potential with environmental attributes degraded completely in individual reaches. It was only possible to measure the restoration and protection value of reaches that were designated as spawning locations.

Several salient patterns for restoration value were shared among species:

(1) Reaches in the lower and middle mainstem of Johnson Creek, as well as lower Crystal Springs have the greatest value for restoration. This is due to the fact that these reaches are used by a larger fraction of salmonids (in at least some part of their life cycle) than reaches higher in the watershed.

(2) There were small decreases in restoration value for all species in almost all reaches since 2000. This demonstrates that Johnson Creek's ability to support salmonids is closer in 2009 to template conditions than it was in 2000.

(3) Middle and upper Kelley Creek had large increases in restoration value since 2000. This is attributable to the fact that they became much more accessible (at least to coho and winter steelhead) from improvements to the obstructions in lower Kelley Creek.

For protection value, most of the reaches that ranked highly were reaches that had undergone restoration. The only prominent exception is Johnson 16, a reach that is closer than most to pristine conditions. It had a high protection value in 2000 and 2009 for both coho and winter steelhead. Three stream segments in which restoration had occurred had negligible protection value in 2000:

lower Kelley Creek, reach Johnson 14 (Schweitzer site), and reach Johnson 5A (Tideman Johnson site). Following the five restoration actions since 2000, the protection value of all of reaches in which project sites were located increased for coho, and two of the three increased for winter steelhead (lower Kelley and Johnson 5A). For fall Chinook, there were no significant changes in protection value, the only measurable change was a small increase in Johnson 5A (Tideman Johnson park).

Two potential effects of restoration were not measured in this analysis, but are important. One is that salmonids that use Johnson Creek but are not part of a population that spawns in the watershed would additionally benefit from restoration in lower reaches of the system. Migrating and rearing juvenile salmon, as well as prespawning adults, from the Clackamas River to the McKenzie River could potentially (and probably do) enter Johnson Creek. They may do so in search of rearing habitat or to escape high velocities or turbidity in the lower Willamette River. In effect, these fish raise the restoration and protection value of reaches in the lower Johnson Creek mainstem and in Crystal Springs. A second important unmeasured effect would be restoration of the lower Willamette River itself. In addition to having the above mentioned effects on upstream salmonid populations, the abundance potential of Johnson Creek would also be improved. While restoration of the lower Willamette has its own set of challenges and limitations, the benefits are particularly high, as seen in our prior analysis of Tryon Creek.

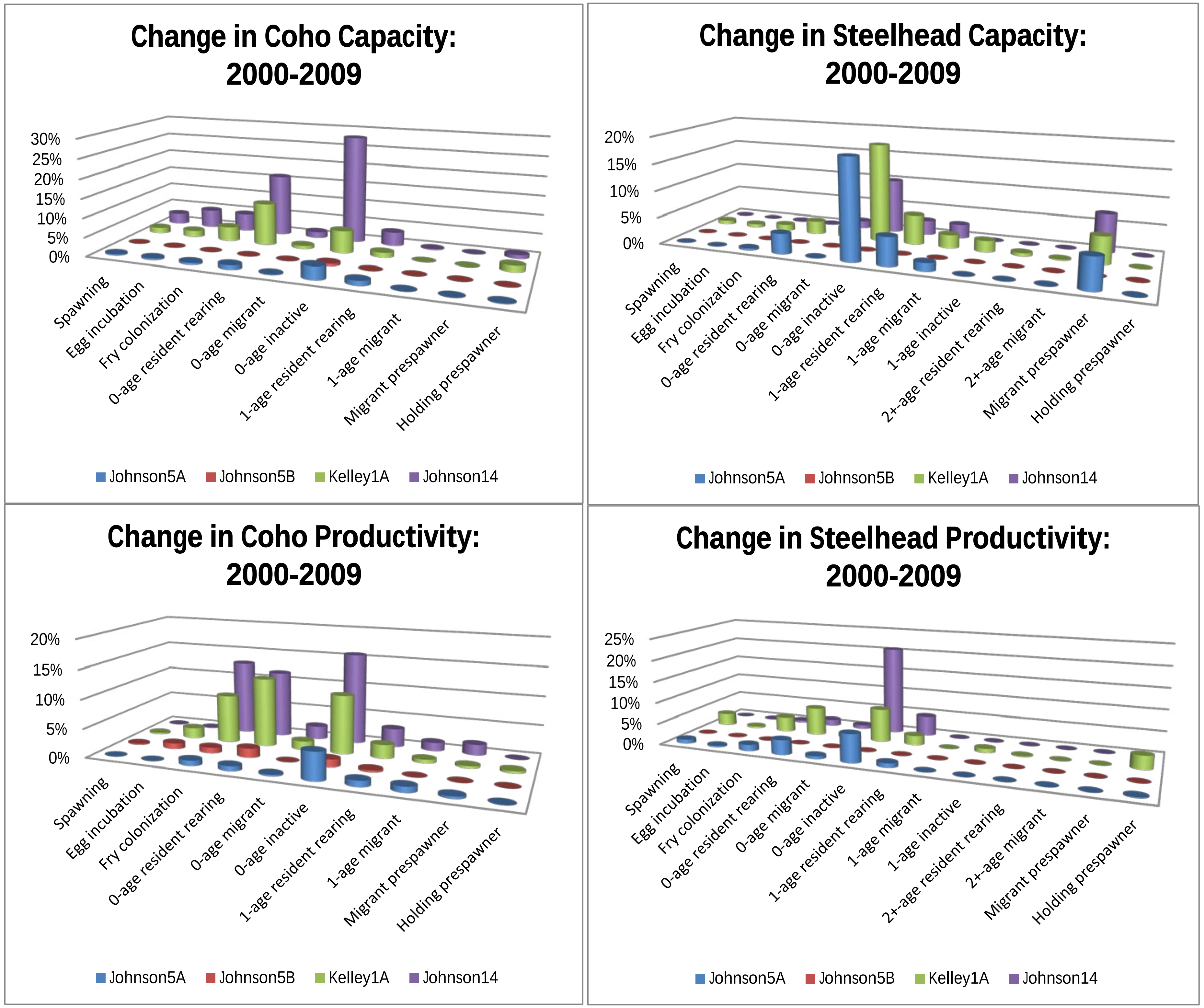


Figure 7. Relative Change in the Productivity and Capacity for Indicator Species in Reaches with Restoration. See Text for an Explanation of Calculations.

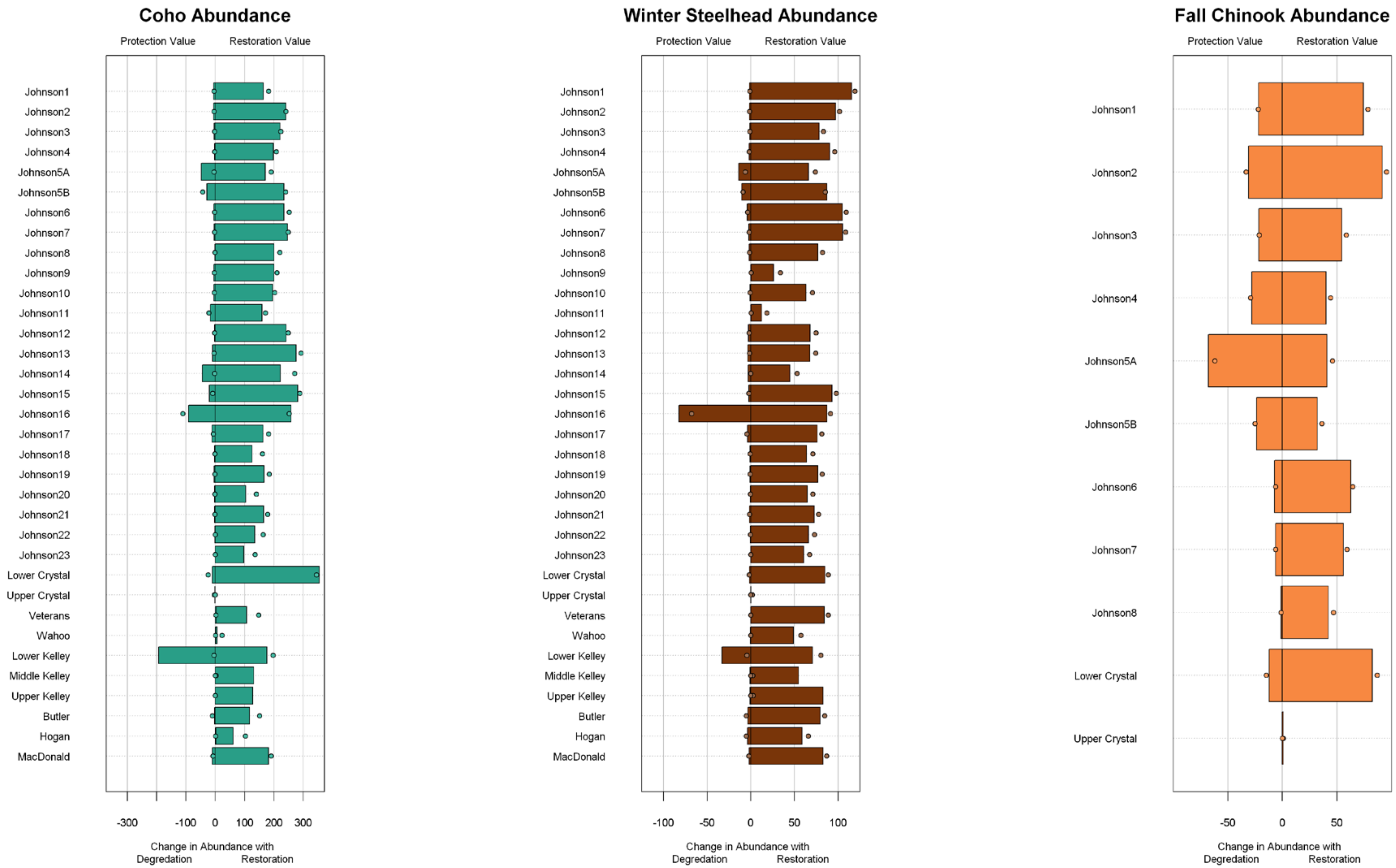


Figure 8 Restoration and Protection Values of Reaches used by Indicator Species in 2000 (dots) and 2009 (bars). These Metrics Depict Change from the Respective Current Value when Template Conditions are Substituted for the Reach.

Conclusions

The results of this analysis indicate that the restoration projects undertaken by the City have substantially increased the potential of Johnson Creek to support ESA-listed salmonid species. The projects considered here are clearly moving the stream in a trajectory toward the City's goal of establishing self-sustaining runs of salmon within Johnson Creek. The projects are providing habitat features consistent with the normative ecosystem as indexed by increased performance of salmonid fishes. Restoration appears to enhance conditions particularly for coho salmon, although conditions are improved to a lesser degree for the two other indicator species, fall Chinook and winter steelhead. We conclude that the benefits of the restoration projects extend far beyond those shown here for salmonids. Fish, wildlife, and plant species characteristic of salmonid ecosystems in the lower Columbia River should benefit from the projects, as well.

Despite the clear increases in habitat potential provided by the City's substantial restoration efforts, habitat in Johnson Creek remains severely compromised with respect to the indicator species. We estimate that habitat potential has been reduced in Johnson Creek for coho salmon by 97% relative to the presumptive historical condition (template). This reduction is due to the cumulative effects of urbanization of the watershed including, especially, the effects of the WPA modifications during the 1930s (Photo 1). This conclusion of continued habitat limitations is bolstered by the absence of evidence of a viable anadromous salmonid population in Johnson Creek. Small numbers of juvenile coho, Chinook, and rainbow trout (potentially steelhead) are found in the stream (Tinus et al. 2003), and there are anecdotal accounts of adult salmonids in the stream. However, it is not clear if the juvenile fish reported in the stream are the result of a self-sustaining population in the stream, or if they move into Johnson Creek from the Willamette River and originate in other streams. All of this leads us to conclude that substantial habitat limitations remain in the stream that will need to be addressed to achieve viable runs of anadromous fish in the stream.

It is unreasonable to expect that fish have responded to the restoration projects to the extent projected here. Two significant lag factors exist in the system. The first is environmental lag time, the time period required for habitat restoration project to mature and produce the equilibrium habitat conditions captured in this analysis. For example, riparian trees need time to grow, while habitat formation (e.g., pools, riffles) requires several seasons of high flow to move gravel and for the system to achieve its dynamic equilibrium state. The second lag factor is associated with the biological response to the environmental changes. Once the habitat features are formed and somewhat stable, the biological community needs to take advantage of the new features and establish the resulting biological community. For example, the benthic insect community needs to develop around the new substrate condition, which, in turn, will provide food for higher trophic levels, including juvenile life stages of the indicator species. The new habitats need to be colonized by adult coho, Chinook, and steelhead. A likely source of these colonists is the extant populations in the Clackamas River including the hatchery programs. Returns from these populations will stray and likely contribute to the formation of viable populations in Johnson Creek.

Finally, it is important to recognize that every salmon life history that begins and ends in the Johnson Creek watershed also involves the lower Willamette River, the lower Columbia River, and the Pacific Ocean. Juvenile coho, in particular, use the lower Willamette as rearing habitat (Friesen 2005). A prior EDT analysis of Tryon Creek indicated that restoration of the lower Willamette magnified changes within Tryon Creek itself (ICF Jones & Stokes 2008). This result has been indicated in Johnson Creek, as well (McConnaha 2003). Contrariwise, conditions in the Willamette River restrict the benefits of restoration projects in tributaries. For this reason, it is worth stressing the need to consider Johnson Creek, along with Tryon Creek and other City streams, as parts of a continuum of habitats that collectively contribute to development of viable populations and ecosystems within Portland.

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