Effects of Dwinnell Dam on Shasta River Salmon and Considerations for Prioritizing Recovery Actions

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Submitted to

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Executive Summary

This executive summary covers only key portions of some of the report sections for the sake of brevity.

Introduction

This document provides the Karuk Tribal Council an assessment of the effects of Dwinnell Dam on the salmon resources of the Shasta River and gives my perspectives for prioritizing possible recovery actions in the subbasin, including dam removal. It is a companion document to one prepared by Tom Cannon that reviews alternatives for achieving salmon recovery objectives associated with a dam removal scenario (Cannon 2011).

The focus of this report is on the Pacific salmon species Chinook and coho, which are indigenous to the Shasta River subbasin. Coho in the Klamath River Basin, as part of the Southern Oregon Northern California Coasts evolutionary significant unit (SONCC Coho ESU), were listed in 1997 as threatened under the Endangered Species Act (ESA).

The Shasta River is one of the most unique river systems anywhere in the Pacific Northwest and Northern California. Historically, it is believed that it was an extremely productive salmon river because of its flow, thermal, and nutrient characteristics. But the story of the Shasta River is similar to many salmon rivers in the west—it has been heavily altered by human development and its salmon populations have suffered huge losses. Similarly, there is hope that salmon can once again thrive in the Shasta River if restoration actions can be sufficiently implemented.

The document is organized into six sections:

1. Introduction;
2. The problem;
3. Concepts for assessing effects and identifying recovery priorities;
4. Assessment of effects – the diagnosis;
5. Solutions – identifying priorities for salmon recovery; and
6. Concluding remarks.

The Problem

Of the three salmon runs produced in the historic Shasta River, one is extinct, another is on the brink of extinction, and the third run has been much reduced from its historic abundance. These losses are the result of a combination of human-caused events and factors operating over the past 150 years. The building of Dwinnell Dam was one of those events, a major one, but its effects have operated in conjunction with others.

For the Klamath basin in its entirety, the abundance and diversity of naturally produced salmon are a shadow of their historic levels. Very large numbers of salmon are believed to have been produced historically in this river basin (Moyle 2002), with some adult salmon returning to the river in virtually every month of the year (Snyder 1931). The Shasta River has consistently been considered to have been a major reason for the prodigious abundance and diversity of salmon in the historic Klamath basin (Snyder 1931; Wales 1951; Moyle 2002; Moyle et al. 2008; Jeffres et al. 2010).

Although quantitative data are lacking for historical production numbers in the Shasta River, there is no doubt that this stream was an exceptional producer of salmon. With its summer flow mainly produced by large springs, emanating from sources rich in geologically derived nutrients, it is certain that the river was highly productive. Flowing through a seasonally hot and dry region, the springs would have maintained thermally optimal conditions for salmon in much of the historic river. The production of fish food organisms would have been extraordinarily high due to the thermal regime, stable flow, and nutrient rich waters.

Jeffres et al. (2010), in a report prepared through the Center for Watershed Sciences at UC Davis, gave this perspective on the river's historic productivity:

> "… the Shasta River historically produced roughly half of the Chinook salmon in the Lower Klamath River watershed while contributing less than one percent of the mean annual flow measured at the mouth of the Klamath River at Orleans (Wales 1951, NRC 2004). This prodigious historical production of salmon was largely related to the unique hydrologic and geologic setting of the Shasta River …"

The Shasta River produced three runs of salmon historically: spring Chinook, fall Chinook, and coho (Snyder 1931; NRC 2004). Peter Moyle at UC Davis believes that spring Chinook were likely the largest run in the subbasin. He has concluded that the Shasta River supported the largest tributary run of this race of Chinook in the entire Klamath basin (Moyle 2002; Moyle et al. 2008). Wales (1951), in his report entitled "The Decline of the Shasta River King Salmon Run", concluded that only about 8% of the entire Shasta Chinook abundance consisted of fall run fish. Based on what we know today about spring and fall Chinook in general, I think it is very likely that Wales' estimate of 8% for fall Chinook was much too low. Regardless, the general views of Moyle and Wales are consistent. Both concluded that spring Chinook was the more abundant of the two races. In the 1930s, by which time spring Chinook had been extirpated in the Shasta River, the abundance of fall run spawners in this river averaged about 39,000 fish. It bears noting that the spawning and rearing habitats in both the Shasta and Klamath rivers by the 1930s were already significantly degraded due to land and water use practices (Snyder 1931; Lichatowich 1999; NRC 2004). It is likely, therefore, that the historic Shasta River supported a much higher number of fall run spawners prior to habitat alterations than it did in the 1930s.

The historic Shasta River also produced a substantial run of coho salmon. No estimates of run sizes exist for the earlier years as they do for Chinook in the 1930s. In my judgment, the river would have been highly productive for this species. Null (2008, citing CDFG 1965 and CDFG 1991) reported a crude estimate of 6,000 coho spawners per year for the river prior to the 1930s, though this figure would have only been an educated guess. The nature of the river—spring dominated flow, nutrient rich water, and many miles of very low gradient river channel—would have produced conditions highly suited to coho (Lestelle 2007). Based on my review of the physical characteristics of the river and an application of coho carrying capacity metrics (from Marshall and Britton 1990, Ptolemy et al. 1994, and Bradford et al. 1997), I estimate that the historic average spawner abundance was likely in the range of 6,000-15,000, and most likely in the upper part of that range. The combination of abundant low gradient habitat, near optimal temperatures, stable flow, and rich food abundance make the higher end of the range more likely.

By the early 1930s, spring Chinook had been extirpated in the Shasta River. Moyle (2002) attributed the demise of the run to the completion of Dwinnell Dam in 1928. The severing of the upper watershed from the lower river by the dam would have been the death knell, but the run was already in decline by that time. Snyder (1931) described how spring Chinook in the Klamath basin in general were in sharp decline prior to 1930 and gave a number of possible reasons. These included mining operations, overfishing (both in-river and in the ocean), irrigation withdrawals, the building of Copco Dam on the upper Klamath River, as well as other factors. In the Shasta River, for example, a low-head hydroelectric dam operated on the lower river near RM 7. Although the dam was equipped with a bypass channel for passing adult salmon, the bypass was not entirely effective—the author stated that it was responsible for the daily destruction of large numbers of adult salmon. But the closure of Dwinnell Dam at RM 40 in 1928 blocked access to major spawning areas in the upper river and to important cold water sources. This was the final straw for Shasta River spring Chinook.

The Shasta River coho population has followed a long-term downward trajectory as a result of the cumulative effects of many habitat alterations combined with fishery mortalities. In listing this species in 1997, NMFS cited water management, water quality, loss of habitat, and overfishing, among other factors, as being responsible for the decline in SONCC coho. These factors without doubt have had significant effects on Shasta coho. But the closure of Dwinnell Dam would have had an abrupt, strong effect on the Shasta population at that time, though not enough to cause the population to collapse. Enough habitat with sufficient quality existed elsewhere in the subbasin to support and maintain the run, but at a lower level of abundance. How the dam would have affected the population is explained further later in this document. The number of adult coho that now return to the Shasta River is typically less than 50 fish.

Regarding the performance of Shasta River fall Chinook, there can be no doubt that it has declined over time, considering data on run sizes and accounting for changes in fishery impacts over time. However, the population is now thought to generally be stable in its performance. It is certain, in my view, that some of the factors that have affected the other Shasta salmon runs have impacted Shasta fall Chinook. It is very likely that Dwinnell Dam has adversely affected the performance of Shasta fall Chinook, continuing to do so, but effects have been much less than on the other salmon runs.

The primary questions addressed in this document are the following:

1. What role did Dwinnell Dam have in the decline of the salmon resources of the Shasta River subbasin, and what role does it continue to have today in the performance trends for existing populations?

2. What priority should be given to dam removal relative to other restoration actions that could be pursued?

Diagnostic Summary

Many factors, acting in concert for longer than a century, are responsible for the steep losses in the salmon resources of the Shasta subbasin. Among these, the construction and operations of Dwinnell Dam have very likely had the most significant effects overall. The effects associated with Dwinnell Dam were direct and immediate, as well as indirect affecting watershed processes that extended the range of effects to stream reaches many miles downstream. The influences of altered watershed processes continue to the present time.

The dam acted to essentially sever the upper part of the main river from the lower and middle parts of the subbasin, significantly altering the natural flow and sediment regimes and blocking all salmon migrations at that point. These effects in themselves would have been disproportionately much greater than others brought about by previous events associated with land and water uses. The severity of disruption to physical, ecological, and biological processes no doubt far exceeded disruptions associated with other prior land and water uses.

It is my view that the building and operations of the dam may have also had a more subtle indirect effect. It is reasonable to think that it contributed to how land owners and water users may have perceived the watershed and its salmon resources. Since the upper watershed was so altered due to the dam and the many changes in brought, more barriers and more water diversions and more disruptions to the streams might have been perceived as having little consequence.

The building and operations of Dwinnell Dam have affected the salmon resources of the Shasta River in the following ways:

- The dam blocked access by spring Chinook to the upper reaches of the watershed—in both the mainstem river and several of its spring-fed tributaries; these areas were likely the core spawning areas of the historic spring Chinook population. This loss of access was the death knell for this population.

- The dam blocked access to approximately 36 miles of stream habitat for coho, most of which would have served as important spawning areas for this species, besides providing both summer and winter rearing habitats.[1] This loss would have resulted in an abrupt and significant drop in coho production following dam construction.

- The reservoir formed by the dam has created a variety of degraded habitat conditions within this body of water, largely related to water quality issues but also associated with seasonal changes in water level. These water quality issues—including elevated water temperatures—influence conditions downstream of the dam due to water releases that occur in summer to satisfy water rights there.

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[1] / I estimate that 36 miles of habitat were likely blocked based on an inspection of topographic maps and stream gradients.

- Water diversions associated with the operations of Dwinnell Dam have greatly changed the characteristics of the flow and sediment regimes in Parks Creek and the Shasta River. These altered regimes have adversely affected salmon habitats in both of these streams in the following ways:
  - Reductions in peak flows in Parks Creek downstream of the water diversion and in the Shasta River between Dwinnell Dam and approximately Big Springs Creek have narrowed and simplified the stream channels, reduced the diversity and quality of instream habitats, and increased the amounts of intra-gravel fine sediments (reducing the quality of the substrate for egg incubation). These changes have adversely affected the quality, quantity, and connectivity of habitats used by coho and fall Chinook.

  - Reduction in the summer flow downstream of Dwinnell Dam have exacerbated high water temperature conditions between the dam and the river mouth due to loss in water mass being discharged by the river (see text associated with Figure 20). These changes have reduced the quality of the existing habitat to support juvenile salmon rearing in the river during the affected months. Consequently, sites of thermal refuge for juvenile coho have become increasingly smaller and more isolated, making it more difficult for juveniles to find the sites and use them successfully during periods of high water temperature.

  - Reductions in flow during all seasons associated with the operations of Dwinnell Dam have reduced the amount of available habitat for all life stages of salmon in Parks Creek and in the Shasta River between the dam and Big Springs Creek.

It is my view that Dwinnell Dam is the single most important impediment to being able to make a successful reintroduction of spring Chinook in the river system. Without access to the upper watershed, the range of habitats that could be available to this species—even with significant habitat restoration in lower Parks Creek and Big Springs Creek—would likely be too small and limited to support this race. It must also be recognized that even with dam removal other habitat issues—including other barriers and diversions—would need to be addressed upstream of the current reservoir to restore spring Chinook.

The effects of the changes in the watershed associated with the Dwinnell Dam and its operations on coho have been pronounced over the past 80 years. While some effects—major ones—were immediate due to blockage of the upper system to coho access, others related to changes in habitats downstream of Dwinnell Dam and the Parks Creek diversion have caused a long-term deterioration in habitats in these areas. These effects have been most significant on the quality of habitats that support coho spawning and egg incubation success and subsequent juvenile rearing and seasonal redistributions. The result of these changes has been to contract—or squeeze—the distribution where coho can survive to a very limited geographic range of habitats. Other land and water uses in these geographic areas, as well as in other areas of the subbasin, have acted in conjunction with the effects associated with Dwinnell Dam. All of these factors operating in concert have brought the coho population to the brink of extinction in the subbasin.

The effects of the factors so detrimental to spring Chinook and coho have been much less on fall Chinook, though the factors likely have still had an important role in reducing performance.

Solutions – Identifying Priorities for Salmon Recovery

In salmon recovery efforts, it is usually more important to rescue and conserve the salmon life histories that currently exist before attempting to recover the ghosts of lost life histories. This principle provides guidance in setting priorities for salmon recovery.

The first priority, therefore, should be to restore normative functions of habitats that are currently within the geographic range of distributions used by coho and fall Chinook in the subbasin. In particular, this priority would be focused on restoring habitats used by coho between Big Springs Creek and Dwinnell Dam and within Parks Creek. Actions would be aimed at reducing the effects of Dwinnell Dam and its operations on habitats in such a way as to expand the range of suitable habitats, including their connectivity during all seasons. This priority might include some aspects of the bypass alternative described by Tom Cannon so that fish could more fully utilize Parks Creek downstream of the existing diversion of water from Parks Creek to the upper Shasta River.

The second priority would be to expand accessible habitat to include more of the historic range of distribution, including those areas upstream of Dwinnell Dam. This priority could include the removal of Dwinnell Dam or implementation of the bypass alternative described by Tom Cannon so that fish could regain access to the upper watershed.

With successful dam removal—or the bypass alternative described by Tom Cannon—along with other restoration activities, a reintroduction of spring Chinook could be planned and implemented.

Conserve and Improve Existing Core Life Histories and Habitats

The first priority should be given to restoring normative habitat functions within the areas currently accessible to coho and fall Chinook in the subbasin. Actions that could be implemented quickly and effectively could rescue the remnant coho population from extinction. To do this would require making a significant improvement in the quality and connectivity of habitats within the geographic range currently used by the population.

The elements of an action plan to achieve these objectives should include the following:

- Continued efforts to restore Big Springs Creek in the manner that actions have already been taken (this level of effort would continue to accommodate flow management from the spring sources as laid out in existing restoration plans);
- Restoration of spring and stream habitats, including their riparian corridors, within the Emerson properties; this would include channel and flow restoration to affected reaches of the mainstem Shasta River and Parks Creek;
- Restoration of a more normative flow regime released out of Lake Shastina to the Shasta River—care would need to be taken to do this in a way not to disrupt the positive effects

of cool water inflows from springs downstream of the dam; among many benefits, this action would help facilitate successful smolt outmigration during the spring period;
- Restoration of a more normative flow regime in Parks Creek by reducing the amount of flow diverted from this stream to the upper Shasta River during winter and spring—this action is believed to be particularly important for facilitating successful smolt outmigration during the spring period; care would need to be exercised in developing an appropriate flow schedule to be restored in Parks Creek;
- Development of an intervention plan using hatchery technology to preserve the existing coho gene pool in the Shasta River, which would include supplementation actions to reduce demographic effects.

The set of actions to accomplish this priority could include aspects of the bypass alternative discussed by Tom Cannon in his report. In concept, it would place significant attention on rebuilding Parks Creek to once again be a core habitat for anadromous fish over much of its stream length.

Expand the Range of Accessible Habitats to Historic Distributions

The second priority would be to expand accessible habitat to include more of the historic range. This priority recognizes that the range of habitat currently used by coho in the Shasta River system is much contracted from what it was historically. There has been a significant loss in spatial structure and habitat diversity that is currently accessible.

I do not see this priority as needing to be addressed only after priority one has been achieved. I believe it is likely some aspects of this priority will need to be met to achieve recovery of coho in the subbasin. In that sense, there is some degree of overlap between the priorities.

As noted above, I think it is likely that successful reintroduction of spring Chinook will require restoration of a large amount of the upper parts of the subbasin, both in terms of access and habitat conditions. Also, while I have not listed it below, it may be necessary to fully restore Big Springs Creek, i.e., full flow restoration, if a spring Chinook reintroduction effort is to be successful.

An action plan to achieve the objective of this priority would include some elements of the following:
- Removal of Dwinnell Dam or development of a suitable bypass alternative through the Parks Creek drainage as described by Tom Cannon (Cannon 2011);
- Restoration of habitat conditions to normative characteristics in the upper parts of Parks Creek and the Shasta River;
- Restoration of access and habitat conditions to other tributaries or parts of tributaries previously used by coho.

Concluding Remarks

The Shasta River historically functioned as one of the most important components of the Klamath Basin’s capacity to produce salmon. The unique characteristics of the Shasta River made it extremely productive for salmon. It must have also contributed considerable genetic and life history diversity beyond what the other parts of the Klamath system produced. Whether viable salmon populations can continue to be supported in the Klamath system for future generations may depend on recovering coho and spring Chinook in the Shasta River.

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Effects of Dwinnell Dam on Shasta River Salmon and Considerations for Prioritizing Recovery Actions

1.0 Introduction

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The focus of this report is on the Pacific salmon species Chinook and coho, which are indigenous to the Shasta River subbasin. Coho in the Klamath River Basin, as part of the Southern Oregon Northern California Coasts evolutionary significant unit (SONCC Coho ESU), were listed in 1997 as threatened under the Endangered Species Act (ESA). The recovery plan for SONCC coho is still in preparation by the National Marine Fisheries Service (NMFS). Klamath River Chinook are not ESA-listed, but NMFS is currently considering listing Upper Klamath spring Chinook as threatened (decision pending at the time this document was being completed).

In addition to having important ecological benefits to both aquatic and terrestrial ecosystems, salmon are highly valued by humans for economic, cultural, and even spiritual reasons. They are an icon of the Pacific Northwest and Northern California. They have been important to the cultures and health of Indian people since time immemorial. There is no doubt that Shasta River salmon were of great importance to several Klamath River tribes—including Karuk people—before the arrival of Euro-Americans; their traditional importance remains high.

Much of the application in this document could similarly be made to the population(s) of steelhead-rainbow (*O. mykiss*) that inhabit the subbasin. Due to the very limited amount of information available on *O. mykiss* in the subbasin, however, I elected to concentrate the discussion on the Pacific salmon species.

I used a qualitative approach for the assessment and to identify priorities, based on my many years of experience in salmon biology, ecology, recovery and restoration planning, and quantitative modeling. A more in-depth quantitative analysis would have required assembling data that are not readily available, use of a quantitative model, and a larger budget than was available for the project. The approach I used is based on qualitatively diagnosing the factors likely to be most important in affecting the performance of Shasta River salmon populations. This was done by assembling available information on patterns of physical and biological characteristics of habitats and populations in the subbasin, then drawing inferences about cause and effect from what we know about fish-habitat relationships from the scientific literature. I have extensive experience in use of fish-habitat relationships in evaluating habitat effects on salmon.[2] Based on this diagnosis and on some key concepts involving population dynamics and

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[2] / I developed all of the rules used in the EDT model to assess effects of habitat alterations on each life stage of coho, Chinook, chum, and pink salmon and for steelhead, cutthroat, and bull trout (e.g., Lestelle et al. 2004).

salmon recovery, I then formulated priorities for salmon recovery actions, of which dam removal is one potential action.

The Shasta River originates in the Eddys (a subrange of the Klamath Mountains) and on Mount Shasta, from where it flows northerly to join the Klamath River at river mile (RM) 177 on that river (Figure 1). It is one of the most unique river systems anywhere in the Pacific Northwest and Northern California. Historically, it is believed that it was an extremely productive salmon river because of its flow, thermal, and nutrient characteristics. But the story of the Shasta River is similar to many salmon rivers in the west—it has been heavily altered by human development and its salmon populations have suffered huge losses. Similarly, there is hope that salmon can once again thrive in the Shasta River if restoration actions can be sufficiently implemented.

The document is organized into six sections:

1. Introduction;
2. The problem;
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2.0 The Problem

Of the three salmon runs produced in the historic Shasta River, one is extinct, another is on the brink of extinction, and the third run has been much reduced from its historic abundance. These losses are the result of a combination of human-caused events and factors operating over the past 150 years. The building of Dwinnell Dam was one of those events, a major one, but its effects have operated in conjunction with others.

For the Klamath basin in its entirety, the abundance and diversity of naturally produced salmon are a shadow of their historic levels. Very large numbers of salmon are believed to have been produced historically in this river basin (Moyle 2002), with some adult salmon returning to the river in virtually every month of the year (Snyder 1931). The Shasta River has consistently been considered to have been a major reason for the prodigious abundance and diversity of salmon in the historic Klamath basin (Snyder 1931; Wales 1951; Moyle 2002; Moyle et al. 2008; Jeffres et al. 2010).

Although quantitative data are lacking for historical production numbers in the Shasta River, there is no doubt that this stream was an exceptional producer of salmon. With its summer flow mainly produced by large springs, emanating from sources rich in geologically derived nutrients, it is certain that the river was highly productive. Flowing through a seasonally hot and dry region, the springs would have maintained thermally optimal conditions for salmon in much of the historic river. The production of fish food organisms would have been extraordinarily high due to the thermal regime, stable flow, and nutrient rich waters.

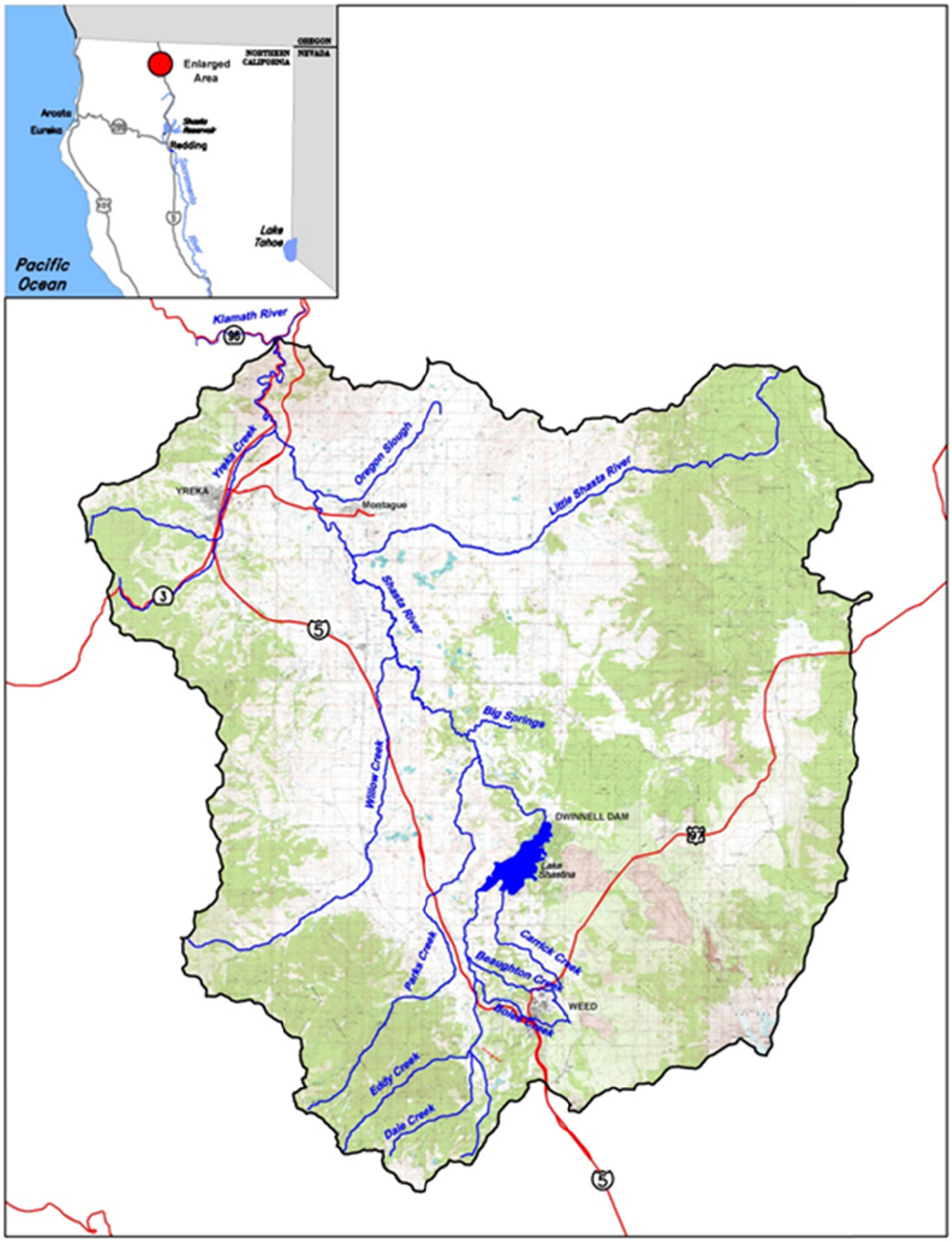

Figure 1. Map of the Shasta subbasin. Taken from SVRCD 2011.

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> "… the Shasta River historically produced roughly half of the Chinook salmon in the Lower Klamath River watershed while contributing less than one percent of the mean annual flow measured at the mouth of the Klamath River at Orleans (Wales

1951, NRC 2004). This prodigious historical production of salmon was largely related to the unique hydrologic and geologic setting of the Shasta River …"

The Shasta River produced three runs of salmon historically: spring Chinook, fall Chinook, and coho (Snyder 1931; NRC 2004). Peter Moyle at UC Davis believes that spring Chinook were likely the largest run in the subbasin. He has concluded that the Shasta River supported the largest tributary run of this race of Chinook in the entire Klamath basin (Moyle 2002; Moyle et al. 2008). Wales (1951), in his report entitled "The Decline of the Shasta River King Salmon Run", concluded that only about 8% of the entire Shasta Chinook abundance consisted of fall run fish. Based on what we know today about spring and fall Chinook in general, I think it is very likely that Wales' estimate of 8% for fall Chinook was much too low. Regardless, the general views of Moyle and Wales are consistent. Both concluded that spring Chinook was the more abundant of the two races. In the 1930s, by which time spring Chinook had been extirpated in the Shasta River, the abundance of fall run spawners in this river averaged about 39,000 fish.[3] It bears noting that the spawning and rearing habitats in both the Shasta and Klamath rivers by the 1930s were already significantly degraded due to land and water use practices (Snyder 1931; Lichatowich 1999; NRC 2004). It is likely, therefore, that the historic Shasta River supported a much higher number of fall run spawners prior to habitat alterations than it did in the 1930s.[4]

The historic Shasta River also produced a substantial run of coho salmon. No estimates of run sizes exist for the earlier years as they do for Chinook in the 1930s.[5] In my judgment, the river would have been highly productive for this species. Null (2008, citing CDFG 1965 and CDFG 1991) reported a crude estimate of 6,000 coho spawners per year for the river prior to the 1930s, though this figure would have only been an educated guess. The nature of the river—spring dominated flow, nutrient rich water, and many miles of very low gradient river channel—would have produced conditions highly suited to coho (Lestelle 2007). Based on my review of the physical characteristics of the river and an application of coho carrying capacity metrics (from Marshall and Britton 1990, Ptolemy et al. 1993, and Bradford et al. 1997), I estimate that the historic average spawner abundance was likely in the range of 6,000-15,000, and most likely in the upper part of that range. The combination of abundant low gradient habitat, near optimal temperatures, stable flow, and rich food abundance make the higher end of the range more likely.[6]

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[3] / The 39,000 value includes precocious males, i.e., jacks or grilse as they have been called in the Klamath River. The average annual adult spawner abundance, excluding jacks, in the 1930s was about 29,000 fish (based on weir counts by CDFG).

[4] / The reader should keep in mind that salmon abundance is not constant over time, even if the freshwater environment has not been degraded through land use practices. Abundance can vary substantially between years and it also exhibits long-term decadal patterns showing oscillations that are somewhat cyclic due to ocean survival patterns and climate effects. Hence salmon abundance can be generally high for an extended period of years followed by relatively low abundance for an extended period.

[5] / The counting weir operated on the lower Shasta River by CDFG was typically removed from the river in the early stages of the adult coho migration into the river due to increasing flows. The purpose of the weir was to enumerate the fall Chinook run size.

[6] Stream systems comprised of a large amount of low gradient habitat, meaning that flow velocities are often very low, combined with stable flow (not highly variable and not subject to flood events) are especially productive for coho (Lestelle 2007). The ability of the stream to yield coho is magnified to an even greater level if the stream is high in inorganic nutrients, which help produce abundant food for rearing juveniles (Ptolemy et al. 1993; Lestelle et al. 2004).

By the early 1930s, spring Chinook had been extirpated in the Shasta River. Moyle (2002) attributed the demise of the run to the completion of Dwinnell Dam in 1928. The severing of the upper watershed from the lower river by the dam would have been the death knell, but the run was already in decline by that time. Snyder (1931) described how spring Chinook in the Klamath basin in general were in sharp decline prior to 1930 and gave a number of possible reasons. These included mining operations, overfishing (both in-river and in the ocean), irrigation withdrawals, the building of Copco Dam on the upper Klamath River, as well as other factors. In the Shasta River, for example, a low-head hydroelectric dam operated on the lower river near RM 7.[7] Although the dam was equipped with a bypass channel for passing adult salmon, the bypass was not entirely effective—the author stated that it was responsible for the daily destruction of large numbers of adult salmon. But the closure of Dwinnell Dam at RM 40 in 1928 blocked access to major spawning areas in the upper river and to important cold water sources. This was the final straw for Shasta River spring Chinook.

The Shasta River coho population has followed a long-term downward trajectory as a result of the cumulative effects of many habitat alterations combined with fishery mortalities. In listing this species in 1997, NMFS cited water management, water quality, loss of habitat, and overfishing, among other factors, as being responsible for the decline in SONCC coho. These factors without doubt have had significant effects on Shasta coho. But the closure of Dwinnell Dam would have had an abrupt, strong effect on the Shasta population at that time, though not enough to cause the population to collapse. Enough habitat with sufficient quality existed elsewhere in the subbasin to support and maintain the run, but at a lower level of abundance. How the dam would have affected the population is explained further later in this document. The number of adult coho that now return to the Shasta River is typically less than 50 fish.

Regarding the performance of Shasta River fall Chinook, there can be no doubt that it has declined over time, considering data on run sizes and accounting for changes in fishery impacts over time. However, the population is now thought to generally be stable in its performance. It is certain, in my view, that some of the factors that have affected the other Shasta salmon runs have impacted Shasta fall Chinook. It is very likely that Dwinnell Dam has adversely affected the performance of Shasta fall Chinook, continuing to do so, but effects have been much less than on the other salmon runs.

The primary questions addressed in this document are the following:

1. What role did Dwinnell Dam have in the decline of the salmon resources of the Shasta River subbasin, and what role does it continue to have today in the performance trends for existing populations?

2. What priority should be given to dam removal relative to other restoration actions that could be pursued?

[7] / Only remnants remain today of the structure.

3.0 Concepts for Assessing Effects and Setting Priorities

This section describes the major concepts that are used in making this assessment and in setting priorities. I have grouped these concepts into four topics:

1. Normative watershed processes and functions;

2. The stock concept and genetics;

3. Viable salmonid populations; and

4. Patient-Template Analysis (PTA).

3.1. Normative Watershed Processes and Functions

Habitats produce natural salmon. They are the templates that organize life history traits, giving rise to life history patterns that enable animal populations to cope with—and even thrive within— constraints imposed by the environment. Hence, a salmon population and its habitats are inextricably linked, which suggests that a population and its habitat should be treated as a single unit, especially in attempts to manage and restore them (Lichatowich 1999). It is essential to have a basic understanding about how habitats are formed and maintained in attempting to recover salmon runs.

A conceptual framework for understanding critical watershed and biological elements that drive natural salmon performance is presented in Figure 2. The framework, based on Beechie et al. (2003), reflects how ecosystems are a dynamic interaction between spatial and temporal variations within larger landscapes. As vegetation, geology, climate, and the spatial distribution of stream reaches—all acting as controls on the system—interface over time, they create variable natural processes that in turn result in a wide range of local environmental conditions. Over millennia, salmon populations adapted to this mosaic of historic environmental conditions (Beechie and Bolton 1999; Beechie et al. 2003), producing diverse life history patterns and performance characteristics of each population within its environment.

An example of one of these watershed processes is the flow (or hydrologic) regime. The flow regime has been called the master variable (Poff et al. 1997)—or in terms used here, the master process. It acts as a major forcer of other processes, such as sediment supply and transport—as such, the flow regime had a major influence on both physical and biological features of historic riverine ecosystems. The flow regime is defined by five characteristics in flow: magnitude, timing, frequency, duration, and rate of change. Over some period of years, these characteristics vary within a range determined by prevailing climate patterns and various watershed features, such as its size, topography, geology, and land cover. Under natural conditions, the patterns and ranges of variation in flow characteristics comprise what is called the watershed's natural flow regime. This regime is the one that a watershed's salmon populations adapted to in the centuries prior to the rapid alterations that occurred over about the past 150 years (Figure 3).

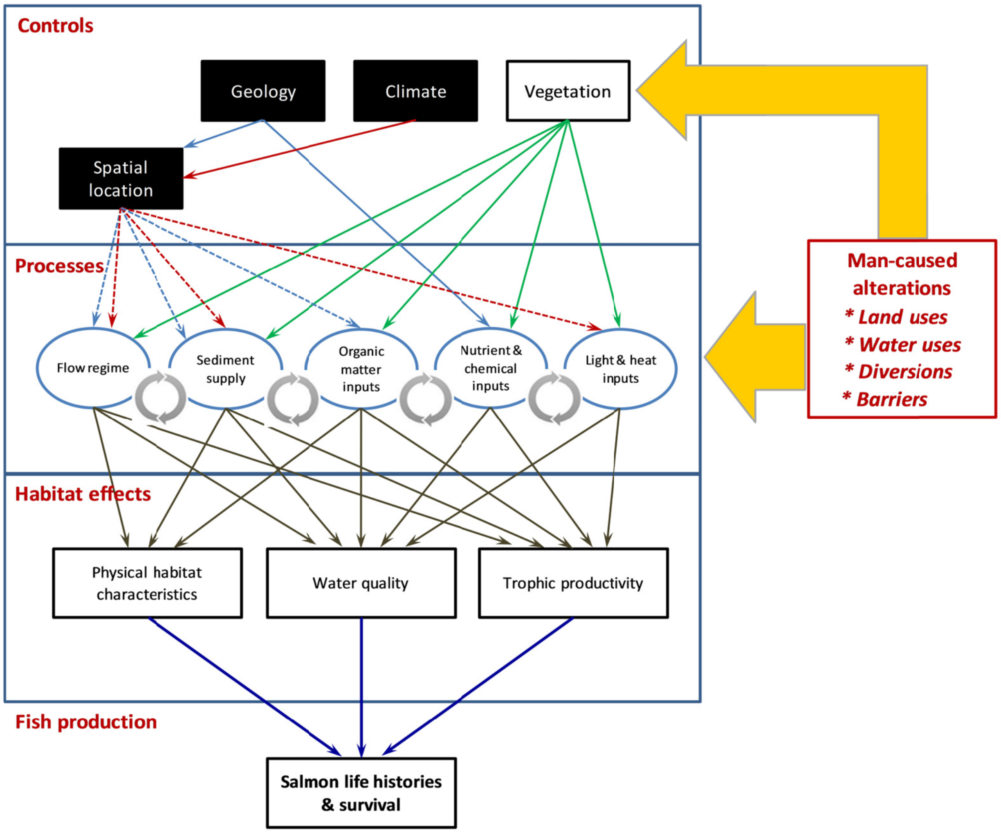

Figure 2. Conceptual framework of critical watershed elements that drive natural salmon performance. Black colored controls indicate that they are not subject to man-caused alterations (at least in the time frame of interest to this report). Adapted from Beechie et al. (2003).

Man's actions also act as controls—in this case external to natural controls, operating in a way that can alter rates of watershed processes, their interactions, and their connectivity. These alterations affect habitat characteristics (including both abiotic and biotic factors) that then change how salmon populations perform. Hence, man's involvement in the watershed produce changes to the characteristics of habitat with regard to its quantity, quality, spatial and temporal distributions, and connectivity—these in turn affect salmon performance relative to the unaltered system.

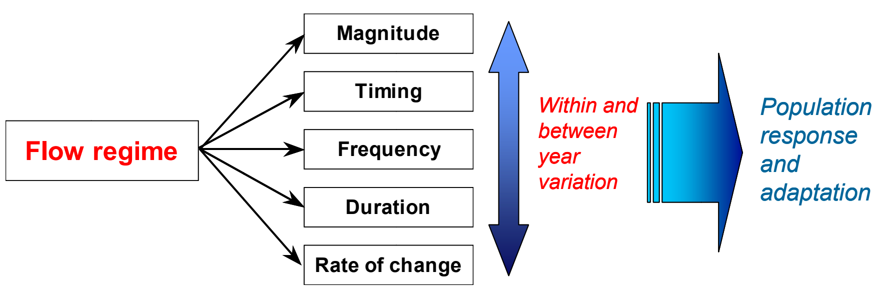

Figure 3. Characteristics of the flow regime, based on Poff et al. (1997).

Dams and water diversions can strongly affect watershed processes and habitats (Stanford et al. 1996; Poff et al. 1997). They are especially disruptive to the flow regime, commonly altering each of the five characteristics of the regime shown in Figure 3. Significant dams also largely disconnect the river system with itself, altering—or worse, severing—both physical and biological processes at the location of the dam. Dwinnell Dam essentially severed the upper river system from the lower river by blocking fish migrations, and it also re-plumbed large parts of the upper river system, radically altering the flow regime and other processes seen in Figure 2.

Salmon recovery is dependent on restoring watershed processes and functions sufficiently to enable salmon populations to be supported and maintained by their habitats (Figure 4). The question arises, however: What level of restoration is needed to adequately restore processes and habitat characteristics needed to recover salmon populations? Methods exist using modeling techniques whereby projections can be made to assess the levels of actions needed to recover salmon (e.g., Thompson et al. 2009). I have been involved in numerous assessments to identify actions for recovering salmon. What can be said short of applying such methods is that watershed processes and habitat characteristics need to be restored to what are sometimes called "normative" conditions.

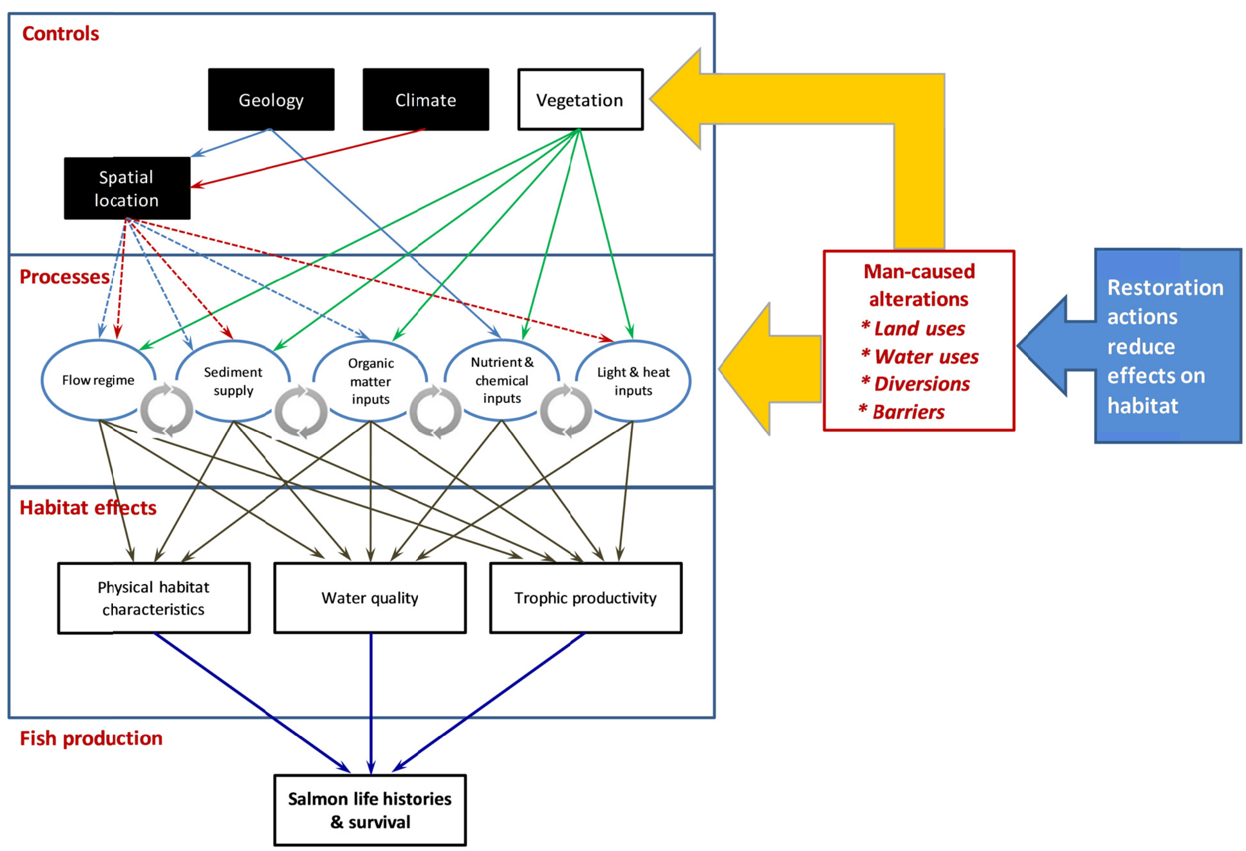

Figure 4. The role of habitat restoration in salmon recovery.

The terms “normative watershed processes” and “normative flow regime” refer to watershed conditions that have been altered by man’s activities but where there is a balanced mix of natural and cultural features such that indigenous life histories of salmon populations can still be supported. These terms, developed for salmon recovery planning in the much altered Columbia River system (Williams 2006; Liss et al. 2006), recognize that modern society causes substantial changes in watershed processes and functions. Still, in many watersheds, ecological processes can be maintained—or restored—sufficiently to support salmon life histories that were historically adapted to them. Normative refers to the norms of watershed processes and functions characteristic of salmon streams. These features, when balanced with society’s needs and demands, result in an ecosystem in which both natural and cultural elements exist in a balance, allowing salmon to recover and thrive sufficiently and many of society’s present uses of the river to continue, although not without modification (Liss et al. 2006).

The question of how much restoration is needed can then be addressed conceptually: Enough restoration is needed to recover life histories of salmon sufficiently so that viability can be assured, while also providing for some level of use of the salmon resource by humans. A watershed with normative processes and functions can sustain all life stages of its indigenous salmon populations. A watershed with such a balanced mix of natural and cultural features is called a normative ecosystem (Liss et al. 2006).

3.2. The Stock Concept and Genetics

Salmon recovery requires the protection and conservation of many distinct population units to minimize extinction risks (Hilborn et al. 2003). Maintaining locally adapted population units within a larger aggregate of related populations is necessary for the long-term health and persistence of the species (Allendorf and Luikart 2007).

Over the past 40 years, it has been established that rivers produce salmon that are numerically and genetically distinct from those produced in other rivers, and that the separate runs need to be conserved as distinct units or stocks. This idea, now widely accepted, came to be known as the stock concept (Ricker 1972). The basic unit, or spawning aggregate, for the purposes of management and conservation came to be referred to as the stock unit, which Ricker (1972) defined as:

> “…fish spawning in a particular lake or stream [or portion of it] at a particular season, which fish to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season.”

Subsequently, Healey and Prince (1995) recommended that the basic conservation unit be expanded to include the population and its habitat. More recently, Waples et al. (2009) drew a similar conclusion for recovery planning.

It is known that different stocks, or populations, of salmon differ greatly in many traits. Quinn (2005) listed some of these traits as follows: spawning migration timing, spawning timing, fat content at the time of return from the ocean, size and number of eggs produced per female, body size and shape of sexually mature males and females, developmental rate and temperature tolerance of embryos, responses of newly emerged fry to the direction of water currents, growth rates, behavioral patterns and duration of residence of juveniles in freshwater, disease resistance, timing of seaward migration, regions of the ocean used as nursery grounds, patterns of age and size at maturity, among others. These differences in traits can be evident among different spawning aggregates within the same watershed.

The accepted working hypothesis in salmon conservation today is that these population-specific traits reflect operation of natural selection on heritable traits (i.e., genetics), with some degree of environmental influence as well (Quinn 2005). Population-specific traits are considered to be "local adaptations" and, therefore, are presumed to improve population performance and long-term viability.

As greater understanding has developed about the genetic diversity of salmon populations, both among and within populations, the importance of conserving gene pools has become more evident (Allendorf and Luikart 2007). Maintaining genetic structure and diversity of small populations that comprise larger population aggregates, or metapopulations, is seen as critical to recovery (Waples et al. 2009; Healey 2009).

3.3. Viable Salmonid Populations

A goal of salmon recovery efforts is to enable salmon populations to maintain themselves within their habitats sufficiently so that the chance of population extinction is negligible. A recovered population is called a viable salmon population (VSP).[8] Viability is assessed through four measurable attributes of a population, defined as follows (McElhany et al. 2000):

1. Abundance – the spawning population needs to on average achieve a certain number of spawners on the spawning grounds to counter environmental variation, demographic effects (low population effects), and genetic inbreeding;

2. Productivity – the population needs to have a population growth rate that is positive when the population is at low levels; a negative growth rate is indicative that the population is going toward extinction;[9]

3. Diversity – the amount of genetic and life history diversity seen in the population, important to counter the effects of environmental variation and inbreeding; and

4. Spatial structure – the population's spatial distribution; greater distribution provides greater resistance to habitat perturbations whether due to land use effects or natural disturbances.

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[8] / A viable salmon population is considered one that has less than a 5% chance of going extinct over a 100 year time frame due to threats from demographic variation, local environmental variation, and genetic diversity changes (McElhany et al. 2000).

[9] / Two different measures of productivity are applied in salmon recovery planning throughout the Pacific Northwest, one that measures population growth rate from generation to generation and another that assesses intrinsic productivity, defined as maximum population growth rate when free of density-dependent limitations. The latter is the productivity measure obtained through a stock-recruitment analysis or through use of EDT model, and is the measure used in this document.

All four VSP attributes are important to recovery—and all four are related. Abundance refers to the average number of spawners in a population over a generation or more. It is affected by the size of the environment that produces the population, i.e., the quantity of the key habitats. Productivity is a closely related attribute, which measures how many adult progeny (or returns) are produced per parent spawner. The relation between these two attributes is illustrated further down in this section.

It is generally thought that a minimum average population size of 500 individuals is needed over the long-term to avoid inbreeding depression and other genetic concerns (Allendorf and Luikart 2007). Franklin (1980) introduced a 50/500 rule of thumb to give guidance on abundance needed to protect against genetic risks. He suggested that a minimum number of 50 for the effective breeding population size was needed in the short-term, but over a longer period a minimum of 500 was needed. Allendorf and Luikart (2007) stated that while this simple rule has often been questioned in the scientific literature, they believe it provides a useful guideline.[10]

Population-level diversity is similarly important for long-term viability. Those populations exhibiting a greater amount of genetic and life history diversity are more resilient to both short-term and long-term environmental changes. Life history diversity, which has some basis in genetics, enables populations to use a wider array of habitats. In doing so, diversity protects against short-term temporal and spatial environmental changes, in addition to providing resilience for persisting through long-term environmental changes. Life history diversity thereby contributes to productivity and to overall abundance as it helps a population more fully utilize its environment.

The fourth attribute, spatial structure, reflects a population's distribution within its environment. Populations with restricted distribution and few spawning areas are at a higher risk of extinction due to catastrophic environmental events than are populations with a greater range of distribution. A population with a more diverse spatial structure, including multiple spawning areas, is also likely to experience more opportunity for gene flow, developmental substructure, and life history diversity. In this way, spatial structure and diversity are closely related. Over multiple generations, greater spatial structure in distribution, associated with more diverse life histories, will tend to produce more stable productivity and abundance levels (Hilborn et al. 2003).

Productivity and abundance are closely linked. It is helpful to understand how they are related using simple illustrations. The concepts will be used later in this report to help prioritize recovery actions for the Shasta subbasin.

Figure 5 displays a spawner-recruit (or spawner-return) (S-R) relationship that may reasonably represent the historic Shasta River coho population. The relationship is a simple conceptual

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[10] / Viability criteria provided by Technical Recovery Teams (TRTs) working on salmon recovery plans often take into account the size of the watershed used for spawning by a population. A larger minimum population size than 500 is believed needed in larger watersheds (NMFS 2010). Also, it is recognized that there is a linkage between abundance and productivity—watersheds with higher productivity could have a smaller minimum population needed to maintain viability with low risk (but not smaller than 500).

model assumed to represent how population abundance (here as returning salmon) varies in relation to the number of reproducing parent spawners. It demonstrates a curve of variable mortality as a function of the parent spawner abundance. Total mortality rate, which consists of two components—density independent and dependent mortality—increases with increasing population density due to progressively greater competition for needed resources (Beverton and Holt 1957). This results in the production curve bending over with larger parent spawner abundance.

Parameter	Historic
Capacity C	6,000
Productivity P	10.0

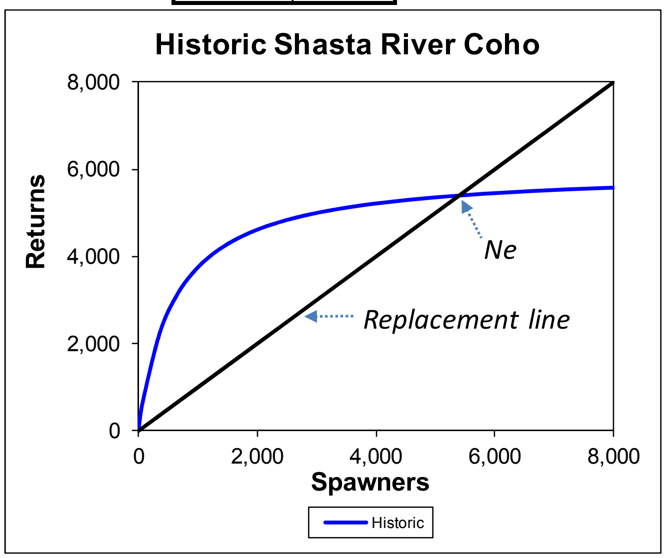

Figure 5. Conceptual relationship between number of spawners and resulting adult returns for the historic Shasta River coho population. Parameter values used reflect reasonable levels to portray possible production characteristics. The N_e value would represent the average river return under steady state conditions.

In Figure 5, the straight line—labeled as the replacement line—identifies the level of progeny production (as returning adults) needed to just replace the number of parent spawners at any level of spawner abundance. Where the S-R curve is above the replacement line, the number of returning adults exceeds the number of parent spawners. Where the curve is lower than the replacement line, the number of returns is less than the number of parent spawners.

If environmental conditions remain more or less unchanged over time, the number of returns will tend to just replace the number of parent spawners, and production will therefore tend to equilibrate at the point where the replacement line crosses the S-R curve. The point where the lines intersect is sometimes called the equilibrium abundance (N_e). In general, this number of returns would be the average run size that one would observe over time (the example reflects what would happen in the absence of fishery interceptions).

The S-R curve depicted in Figures 5 and 6 is determined entirely by two parameters, called capacity (C) and productivity (P). For this example, I have set the parameters at values that might reasonably be assumed to represent the historic Shasta coho population (though I have used conservative values here). In this case, I set the capacity value at 6,000 fish, meaning that the average maximum number of returning adults would be about that number. Actually, the equilibrium abundance in this case turns out to be about 5,800, which is where the lines intersect. This value is roughly the lower end of the range I reported earlier for the average historic coho run size in the Shasta River. The capacity parameter defines the limit of how large the population can grow as determined by the size of the environment (here the amount of available habitat).

Parameter	Historic
Capacity C	6,000
Productivity P	10.0

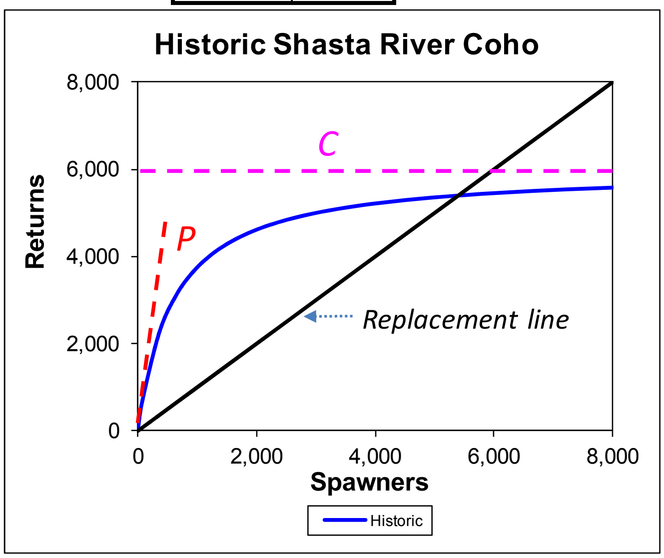

Figure 6. Portrayal of the productivity and capacity parameters on the production curve. See text.

The second parameter, productivity (or intrinsic productivity), sets the angle of the curved line at the point where the curve begins at the origin of the graph (i.e., at zero spawners) (Figure 6). This angle is extremely important to defining how productive the population is. The productivity parameter identifies the rate of progeny production at low spawner abundance.[11]

The two parameters represent how the two characteristics of habitat affect survival. Capacity defines the size of the environment, i.e., the *quantity of the habitats*. Productivity defines the level of survival when fish are not competing with each other for resources—this survival rate is determined by the *quality of the habitats*. How the population is affected by both habitat quantity

[11] / Intrinsic productivity is expressed as the number of returns produced per parent spawner at low spawner abundance. It also reflects the component of the natural mortality operating on the population (or conversely the density-independent survival rate) when competition for resources is not a factor affecting population performance. It is important to note that the discussion here about productivity does not consider what is called "depensation", which can occur when spawner abundance drops to an extremely low level. Below such a point, the productivity value, or reproduction rate, can drop to a lower level due to such issues as spawners not be able to find one another to mate due to very low spawner densities. In the 50/500 rule-of-thumb described earlier, depensation might occur below a level of 50 spawners.

and quality is what determines population performance, here measured as abundance (the actual number of fish that return to the river).

The *quantity* of habitats is determined by such characteristics as total amount of living space available in the key types of habitats used by a species. Habitat quantity also reflects the total amount of available food needed to sustain a population at a level when individuals compete with one another for that food.

The *quality* of the habitats is determined by such attributes as water temperature, fluctuations in water flow affecting behavioral patterns, habitat structure affecting predation rates on the population, the probability of an individual fish finding suitable habitat (as determined by the distribution of habitats), dissolved oxygen levels, the amount of fine sediment within spawning gravels (affecting embryo survival), and the diversity and density of food as it would affect survival of even a few fish present.[12] Many other attributes of habitat quality exist (Lestelle et al. 2004). All of these attributes characterize aspects of the environment that fish are not competing for.

It is easy to conceptualize from Figure 6 how population performance is the direct result of habitat characteristics that exist within a river system. Changes in either habitat quantity or quality will affect the average abundance of the population over some period of time.

3.4. Patient-Template Analysis (PTA)

To effectively identify actions needed to recover salmon populations, it is imperative to first determine the critical factors that must be ameliorated by those actions. A Patient-Template Analysis, or PTA, is a method for doing that (Lichatowich et al. 1995). It provides the basis for identifying and prioritizing actions aimed at habitat restoration for reversing salmon declines and moving toward recovery.

The PTA is in simple terms a comparative description of the historical and current habitats used by a salmon population, together with a description of historic and current life histories of the population. It assesses in some fashion the change in population performance between historic and current conditions due to habitat alterations. The approach uses a medical analogy to compare existing conditions of the populations and their habitats (the patient) with the known—or presumed—historic conditions (the template). The comparison between the patient and its template leads to a diagnosis, which is a reasoned hypothesis about the causes of the decline in the patient. This hypothesis is used to identify potential treatments, providing the essential rationale that needs to accompany any action plan for recovery. Much like a lot of modern medical treatment on humans, well planned salmon recovery efforts require having a sound, well-reasoned hypothesis about a diagnosis and the treatment plan. The hypothesis should be properly documented for the sake of promoting scientific progress.

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[12] / The quality of food items (such as by the diversity of food) and their density can affect the performance of juvenile salmon even at very low abundance of juveniles. In effect, this means that food can be considered as part of both the quality and quantity of habitat (food is a part of a fish's habitat).

The PTA method can be applied quantitatively—using such models as EDT (Lestelle et al. 1996; Mobrand et al. 1997, Blair et al. 2009), or it can be used qualitatively taking more of a narrative form (e.g., Lichatowich et al. 1995; Lichatowich 1998). The EDT model has been used throughout Pacific Northwest in scores of applications on many river systems for this purpose. Where time and resources exist for applying such a modeling approach, it provides detailed information for developing comprehensive analysis for recovery planning.

The same concepts can be applied without use of the quantitative model. In this case, a qualitative analysis is formulated by summarizing and synthesizing various types of information into a narrative form. This can be used to develop a well-reasoned diagnosis about the salmon populations of interest and the condition of their habitats, from which an action plan can then formulated (Lichatowich et al. 1995; Lichatowich 1998).

I developed a Patient-Template Analysis for the Shasta River salmon populations with the information that I could retrieve from various documents. With more time, a more comprehensive analysis could be performed; though I believe what I have developed here provides a solid basis for deriving a diagnosis and identifying action priorities.

4.0 Assessment of Effects – The Diagnosis

This section provides a diagnosis of the Shasta River subbasin with regard to salmon population performance. It is organized into three subsections:

- Shasta River description;
- Life history patterns and spatial use of the river;
- Limiting factors; and
- Diagnostic summary.

4.1. Shasta River Description

This section reviews important features of the Shasta River and its habitat characteristics that are likely relevant to the way that salmon perform in the subbasin.

4.1.1. Geology, Topography, Riparian Features, and Climate

Set within the large, diverse Klamath River Basin, the Shasta River subbasin is one of the most unique watersheds anywhere within the Pacific Northwest and Northern California. Its most unique characteristic, similar to only a few other watersheds of substantial size in this geographic region, is its flow regime, which to a great extent is produced by springs. The Shasta River receives more than half of its annual flow from spring complexes (Jeffres et al. 2009).

The Shasta River, draining 793 square miles, originates in the Eddys (a subrange of the Klamath Mountains) to the south and west and the Cascade Volcanic Range to the south and east. The Shasta subbasin is virtually identical in size to the neighboring subbasin to the west, the Scott River, though the former generates significantly less runoff than the latter due to its much drier climate.

The river originates on the north slope of Mount Eddy, though runoff from Mount Shasta in the southeast corner of the subbasin contributes significantly to the surface water and groundwater hydrology of the subbasin. Elevations in the subbasin range from the high of 14,162 feet at the peak of Mount Shasta to the low of 2,020 feet at the river mouth. The Shasta River joins the Klamath River at river mile (RM) 177 on that river.

Like the Scott subbasin to the west, the Shasta subbasin has a large central alluvial valley, steep headwaters on the west and southwest, and a rugged gorge in the lower end of the subbasin prior to its connection to the Klamath River.

The total length of streams in the subbasin, including the main Shasta River and its tributaries is listed as approximately 110 miles (ESA 2009). The mainstem river is approximately 55 miles in length. Significant tributaries include Boles Creek (RM 50), Beaughton Creek (RM 49), Carrick Creek (RM 43), Parks Creek (RM 35), Big Springs Creek (RM 34), Willow Creek (RM 25), Little Shasta River (RM 16), and Yreka Creek (RM 8). The topography through which these streams flow varies greatly, from flat plains with few topographic features to steep, mountainous terrain.

The Shasta River flows for most of its length along the floor of Shasta Valley downstream of Dwinnell Dam (RM 40). Between the vicinity of Big Springs Creek (RM 34) to the vicinity of the town of Yreka near RM 10, the river channel is quite flat, dropping in elevation extremely slowly. Over most of this distance, the river exhibits what Nichols (2008) called a "tortuously meandering" pattern, reflecting its very flat gradient. The substrate along this section is composed of silts, sands, and small gravels, and the channel lacks exposed point bars at low flow (Nichols 2008).

The mainstem Shasta River over most of the distance downstream of Dwinnell Reservoir is largely exposed to solar radiation with relatively little shading provided by riparian vegetation. The river channel is relatively narrow, and if trees were present, they would be quite effective in giving shade to the river (Null 2008). Riparian surveys conducted in the mid-1990s showed a low density of trees in most areas, and many reaches were completely barren of trees (Deas 1997). Grazing and agriculture have occurred through much of the valley since the 1800s, so it is not well understood what the riparian condition was along the river prior to this period. However, Null (2008) states that it is unlikely that a full gallery forest along the length of the Shasta River existed prior to grazing due to anoxic soils. Abbott (2002) found, based on field surveys, that bulrush was the dominant vegetation along the river where protection from grazing by fencing occurred, which provides virtually no shading.

The prevailing climate in the subbasin is semi-arid but precipitation varies greatly depending on location. Annual precipitation ranges from less than 15 inches on the main valley floor to over 45 inches in the Eddy and Klamath Mountains (ESA 2009). Air temperatures on the valley floor are typical of California's Mediterranean climate—hot summers and cool winters.

On Mount Shasta, precipitation ranges from 85 to 125 inches (WRCC 2007 and NCRWQCB 2006, cited by ESA 2009)—much of the winter precipitation falls there as snow. Mount Shasta has permanent glaciers, as well as a snow pack that usually persists to varying degrees on a year-round basis (ESA 2009). It is one of the very few mountains in North America where glaciers are known to be growing and not shrinking (http://www.westernjournalism.com/glaciers-growing-on-mt-shasta/).

4.1.2. Flow Sources and Water Development

Schematics of the historic and current Shasta River, showing entry points of its major tributaries, locations of major spring sources, and, for the current condition, locations of major water diversions and Dwinnell Dam, are provided in Figure 7. Locations of tributaries and other features along the mainstem Shasta River are indicated by river mile along the river. Shown on the historic schematic is an area of marshes in the vicinity of RM 40 – 43, which is the area now inundated by Dwinnell Reservoir. Mike Deas (Watercourse Engineering Inc., *personal communication*) has concluded on the basis of reviewing old maps that prior to dam construction this area likely contained considerable marsh habitat.

The schematics also show approximate locations of major springs in the subbasin, but numerous other smaller springs also exist. By far, the greatest amount of spring-generated flow comes from the upper half of the subbasin, emanating from porous geologic features along the lower flanks of Mount Shasta. The largest spring complex in the subbasin produces Big Springs Creek (RM 34), which is believed to have been the source of over half the Shasta River flow during late summer in the historic river (Null 2008). Before water development, it is estimated that Big Springs Creek supplied approximately 100 cfs of cool water to the Shasta River (Mack 1960). Currently, the creek supplies less than half that volume of flow in summer due to the effects of water diversions and groundwater pumping associated with irrigation (Jeffres et al. 2010). In many recent years, approximately 95 percent of summer baseflows in the lower Shasta River originate from Big Springs Creek (Nichols et al. 2010).

The springs that feed Shasta River keep the river cooler in summer and warmer in winter than it would be without spring influence. This pattern would have had especially pronounced in the historic river. Without the spring influence, streams in this general area are particularly warm in summer and cold in winter, conditions that severely limit salmonid production. The spring sources that feed Big Springs Creek emerge at constant temperatures between 10-12°C (Jeffres et al. 2010), which would have produced nearly ideal conditions for salmon growth in the creek prior to land use alterations. Other springs in the upper Shasta subbasin have a similar temperature regime at their sources. Under historic conditions, the large amount of flow produced in Big Springs Creek would have made a short transit time to the Klamath River (less than one day), which should have kept the Shasta River relatively cool over this distance (NRC 2004).

It is important to note that until recently water development combined with grazing practices in and along Big Springs Creek was having significant adverse effects on water temperature within the lower end of the creek. Virtually no riparian vegetation, together with the reduced flow in the creek associated with irrigation, resulted in relatively rapid warming of the stream downstream of the spring sources. The effect was that the creek entered the Shasta River at some times during summer at 25°C (Null 2008; Nichols et al. 2010). In this condition, any beneficial effect of cooling by the spring complex was being negated—in effect, the creek had become a source of a large volume of warm water being added to the river. In the past two years, this situation has been greatly improved by restoration activities, as explained later in this section.

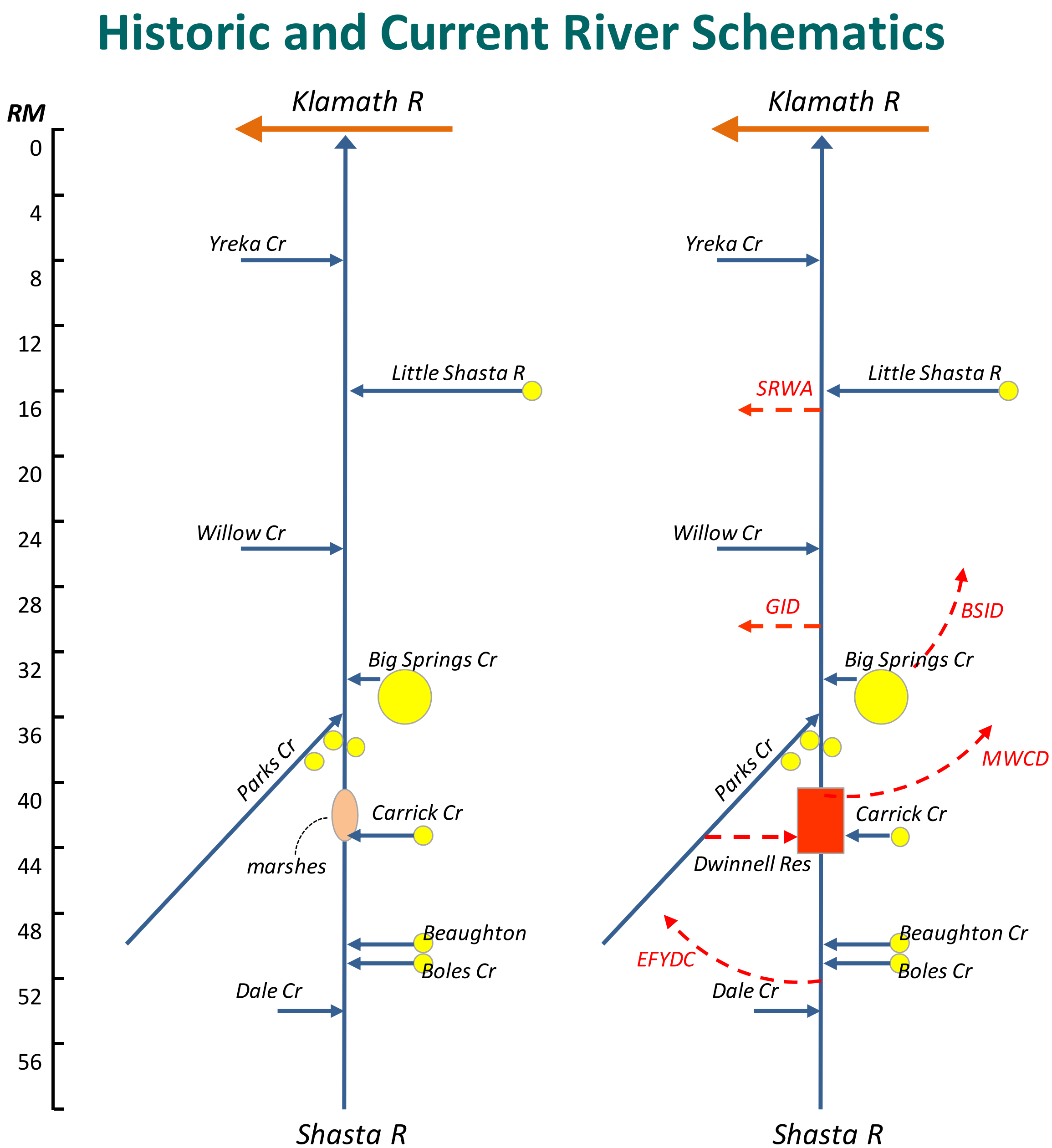

Figure 7. Schematics of the historic and current Shasta River showing entry points of major tributaries, major spring sources, and other important features. Yellow circles indicate major spring sources, with the largest being Big Springs Creek indicated by the large yellow circle. Major water diversions are shown for the current river. Abbreviations are the Shasta River Water Association (SRWA), the Grenada Irrigation District (GID), the Big Springs Irrigation District (BSID), the Montague Water Conservation District (MWCD), and the Edson-Foulke Yreka Ditch (EFYDC).

Besides the abundance of cool water produced, the Big Springs complex supplies an unusually rich source of geologically derived nutrients to the stream. It is estimated that the groundwater producing the spring complex takes 20-50 years to move from its above-ground original sources to the springheads feeding Big Springs Creek. During this time, the water is enriched by both nitrogen and phosphorus released from the underlying marine sedimentary and volcanic rocks at the base of Mount Shasta (Dahlgren et al. 2010). These nutrients, combined with the stable abundance of cool water, fuel the high rates of primary productivity in the stream, resulting in extraordinary aquatic invertebrate production, especially of amphipods, but the benthos is also notably diverse (Jeffres et al. 2009). The other springs that originate on the flanks of Mount Shasta are also thought to be rich in these nutrients (Vignola and Deas 2004).

Other significant springs in the upper parts of the subbasin and downstream of Dwinnell Dam are Clear Spring on the Shasta River (located upstream of Parks Creek) and Kettle Springs and Bridgefield Spring complex along lower Parks Creek. Other smaller unnamed springs also exist (Chesney et al. 2009; Davids Engineering 2011). It should be noted that there is reason to suspect that the Bridgefield Spring complex on Parks Creek has been enhanced by the Dwinnell Reservoir due to leakage.

Upstream of Dwinnell Dam, significant spring sources feed Carrick Creek, which enters Dwinnell Reservoir, Beaughton Creek, and Boles Creek. Other smaller, unnamed springs feed other headwater areas of the upper Shasta River. Parts of upper Parks Creek are also fed by springs.

There are four major diversions from the Shasta River; each is shown in Figure 7. They are the Shasta River Water Association (SRWA), the Grenada Irrigation District (GID), the Big Springs Irrigation District (BSID), and the Montague Water Conservation District (MWCD). The MWCD, the largest water user in the subbasin, diverts water straight from Dwinnell Dam (Lake Shastina) into the MWCD canal. As part of that project, water is also diverted from Parks Creek to the upper Shasta River, from where it flows into Lake Shastina (shown on the schematic as flowing directly to Lake Shastina). Also shown on the schematic is a diversion from the upper Shasta River, the Edson-Foulke Yreka Ditch (EFYDC), which contributes to the Yreka Ditch that goes to the lower valley.

Many other smaller diversions also exist along the Shasta River and its tributaries (Figure 8).

Dwinnell Dam, completed in 1928, inundated an area of approximately 2.8 square miles and about 3.8 miles of the historic Shasta River channel. Lake Shastina, formed by the dam, is a eutrophic reservoir with a summer thermal stratification pattern and an anoxic bottom layer. The reservoir has a high nutrient content reflecting both inflow and internal nutrient processes (Vignola and Deas 2005). The surface layer warms considerably in summer but the bottom layer (while the lake is stratified) is cool. The thermal stratification can break down in late summer, though it typically does so in fall or early winter (Vignola and Deas 2005). The bottom layer tends to be very depleted in dissolved oxygen.

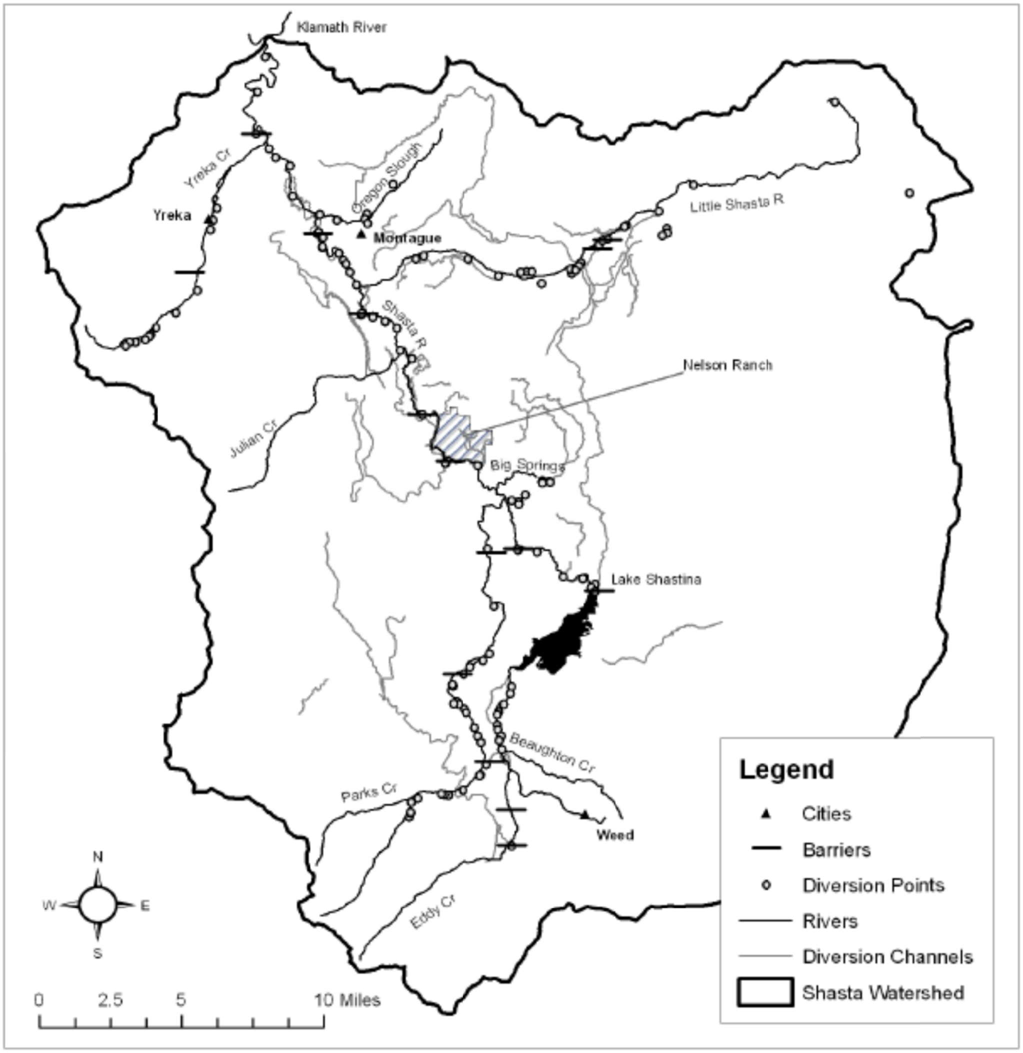

Figure 8. Water diversion points and barriers along the Shasta River and its tributaries. Taken from Null (2008).

4.1.3. The Flow Regime

The Shasta River receives more than half of its annual flow from springs that sustain year-round baseflows (Jeffres et al. 2010). As a result, flow characteristics differ widely within the subbasin depending on location with respect to flow sources. Water management practices over the past 150 years have substantially altered the various flow regimes in the subbasin.

Uncertainty exists in some aspects of the historic flow regimes because of the lack of flow data prior to the advent of water management using water diversions. Still, many of the characteristics of the historic regimes can be inferred from available flow data and knowledge about major flow diversions, climate patterns, and geomorphic features.

Estimates of average daily flow by month for unimpaired hydrographs have been developed at various times in the past (e.g., CDWR 1964; Owens and Hecht 1998; Deas et al. 2004; Null

2008). The unimpaired hydrograph is meant to represent what flow levels were prior to groundwater pumping, construction of Dwinnell Dam, stream impoundments, diversions and land use changes. In the most recent work, Null (2008) expanded on the modeling procedure used by Deas et al. (2004) and provided estimates of unimpaired daily flow by month at several locations and major tributaries in the subbasin (Figure 9). These estimates, despite some uncertainty due to the nature of the modeling procedure, are probably reasonable representations of the shape of the hydrographs at various sites and of seasonal flow magnitudes with perhaps a few exceptions.

The patterns seen in Figure 9 illustrate major differences in flow regimes between locations. The upper Shasta River (represented at the Dwinnell site) and Parks Creek have winter and spring dominated runoff patterns with seasonal low flows in late summer and early fall. I would note that the flow level shown for Parks Creek in late summer appears to be too low; Null (2008) gave an average daily flow value of 6 cfs in August. However, Davids Engineering, Inc. (2011) found that Kettle Springs, a spring-fed tributary to lower Parks Creek, produces 8 cfs alone—thus it seems that the historic average low flow in Parks Creek must have been at least 14 cfs.[13]

There are reasons to suspect that the estimates of unimpaired flows may be conservative. The approaches used to estimate the unimpaired flows all have relied mostly on California Department of Water Resources (DWR) service records, which document known water diversion rates at various sites. The records only apply to water being diverted as part of appropriative rights. Riparian water rights in the Shasta River subbasin are not adjudicated and are not regulated by the watermaster.[14] No records are available documenting volumes of water being diverted as part of riparian rights. Also, the adjudication of water rights in 1932 did not address groundwater pumping. In addition, other natural, smaller accretions of water likely occur along the Shasta River downstream of Dwinnell Dam and these do not appear to be included in the flow reconstructions. Deas et al. (2004) suggested that such accretions were likely small historically, having only a minor effect on the reconstructions. All of these factors combined, however, suggest that the unimpaired flow estimates may be conservative.[15]

Interannual flow variation in the Shasta River natural flow regime differed greatly by location within the historic subbasin. Figure 9 shows, for example, that flow generated in Big Springs Creek was highly consistent between seasons prior to water management. That was not the case for flows generated in other parts of the upper subbasin. Figure 10 shows daily flows in two years in the mid-1960s at the Edgewood USGS gauge station on the upper Shasta River (RM

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[13] / Davids Engineering, Inc. (2011) reported that Kettle Spring generated about 6 cfs in July during the peak growing season in nearby pastures and 8 cfs in September. It appeared that there was an effect of land use on reducing the spring output in some months.

[14] / Riparian rights to divert water usually come with owning a parcel of land that is adjacent to a source of water in California. A riparian right entitles the landowner to use a correlative share (i.e., limited to a reasonable amount) of the water flowing past his or her property. Riparian rights do not require permits, licenses, or government approval, and they apply only to the water which would naturally flow in the stream. Riparian rights remain with the property when it changes hands, although parcels severed from the adjacent water source generally lose their right to the water. Riparian rights have a higher priority than appropriative rights.

[15] / Mike Deas (personal communications) has concluded that the flow volumes generated by the springs has been variable over decadal time as a result of natural fluctuations.

48).[16] It should be noted that the flows passing this point on the river in the winter and spring are a combination of flows produced in the upper Shasta River as well as from upper Parks Creek. Water is diverted from upper Parks Creek to the upper Shasta River upstream of the gauging station for storage in Lake Shastina. The figure illustrates the extent of interannual variation reflected in the combined flow pattern during winter and spring in these two streams.

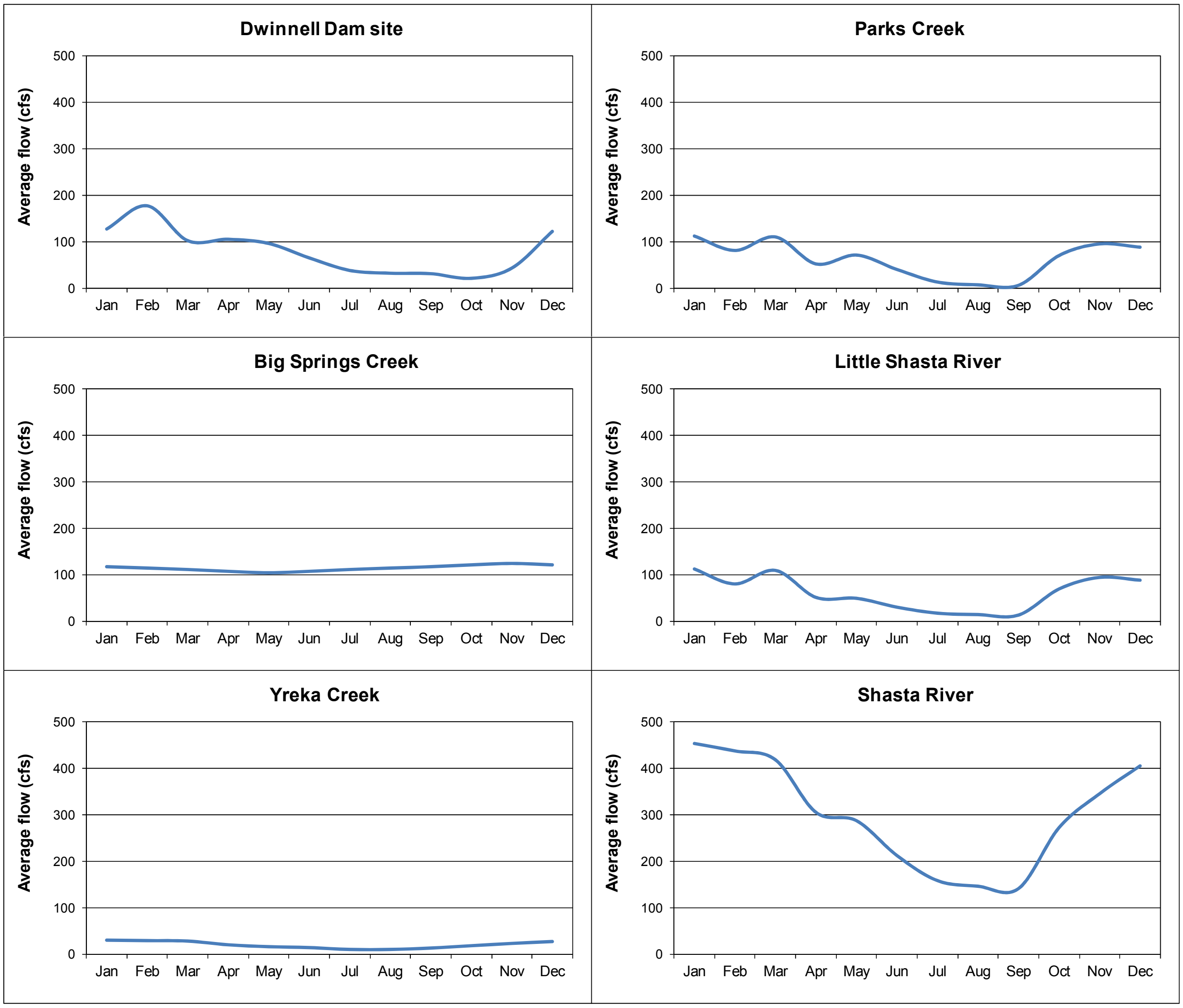

Figure 9. Shapes of historic hydrographs showing seasonal patterns and approximations of flow magnitude (average daily flows by month). Adapted from Null (2008).

The flow regimes in the upper Shasta River and in Parks Creek are best characterized as having a flashy hydrology with high seasonal variability and low baseflows (Nichols 2008). These characteristics reflect runoff-dominated streams, common to salmon producing streams on the

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[16] / Only five consecutive years of flow records exist for the Edgewood gauging station, water years 1963-1967. Data for a few older, non-consecutive years also exist. No other continuous gauge records exist for the upper Shasta system.

West Coast. As a result, the channel forms and substrate sizes in the upper Shasta River and Parks Creek are principally driven by their elevated channel slopes and their flow regimes associated with rainfall and snowmelt runoff (Nichols et al. 2010). Such channels are typically laterally active, meandering gravel-bedded streams with pool and riffle habitat types. They provide abundant spawning habitat for salmon, as well as shallow, protected sites for newly emerged fry and main channel pools used by larger juveniles. These were the conditions that would have existed in much of the upper Shasta River upstream of Big Springs Creek and in Parks Creek prior to water management.

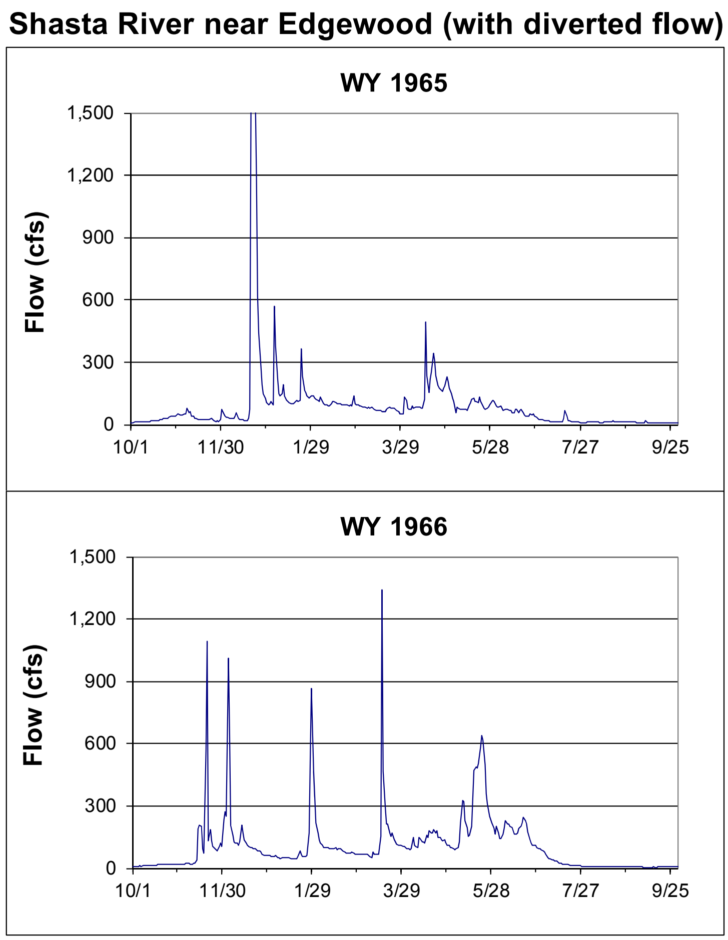

Figure 10. Daily average flow at the Edgewood USGS gauging station on the upper Shasta River (RM 48) for water years (WY) 1965 and 1966. The flows at this point on the river include water diverted from upper Parks Creek to help fill Lake Shastina.

The characteristics of the historic natural flow regime downstream of Big Springs Creek are different from those upstream as a result of different landforms and the addition of Big Springs Creek flow. Nichols (2008) said the flow regime there had hybridized characteristics due to combining a spring-dominated system with a run-off dominated system. Downstream of Big Springs Creek, historic flow variability was strongly reduced by all of the accretions of springs in the general vicinity, particularly those that feed Big Springs Creek. Most notably, summer baseflows in the historic river remained remarkably consistent as a result of the stable flows from the springs.

Water management, which began in the 1850s to support mining, has had an enormous effect on the natural flow regimes. Flow routing has been significantly altered to support agricultural activities. A significant amount of water produced by the subbasin is also lost through land use activities, thereby reducing the amount of runoff that leaves the subbasin to join the Klamath River (Deas et al. 2004). Flow levels at the lower gauging station on the Shasta River (RM 0.7) have been reduced significantly in every month of the year, based on comparison of modeled unimpaired flows and observed average monthly flows (Figures 11-12). The observed flows in Figures 11-12 are average daily flows by month for 1991-2010. The reduction in annual runoff corresponding to the data used in Figures 11-12 is about 40%. Deas et al. (2004) reported that CDWR (1998) listed a loss in annual runoff of 39% for the period 1945-1994.

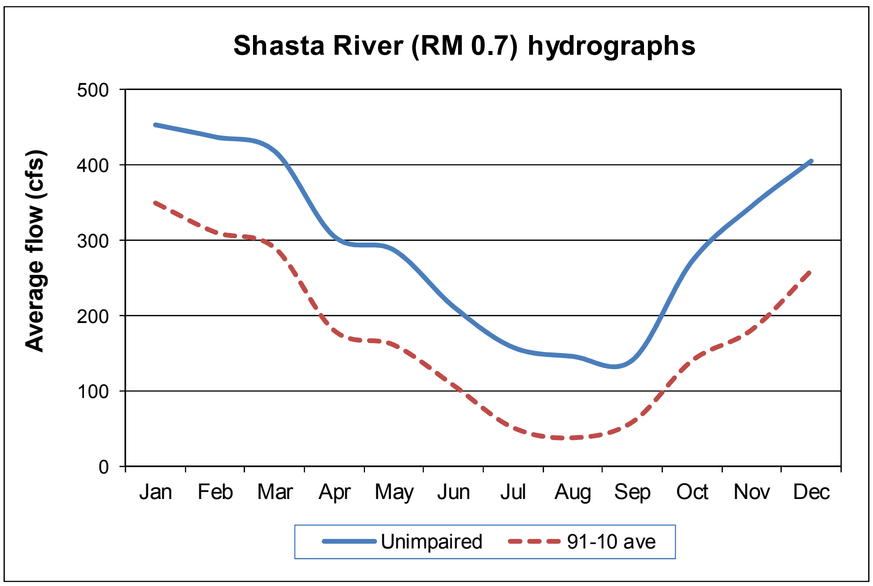

Figure 11. Estimated average daily flow by month for the historic unimpaired hydrograph at RM 0.7 on the Shasta River (from Null 2008) and the observed average daily flow by month derived from USGS gauging records at the same point for years 1991-2010.

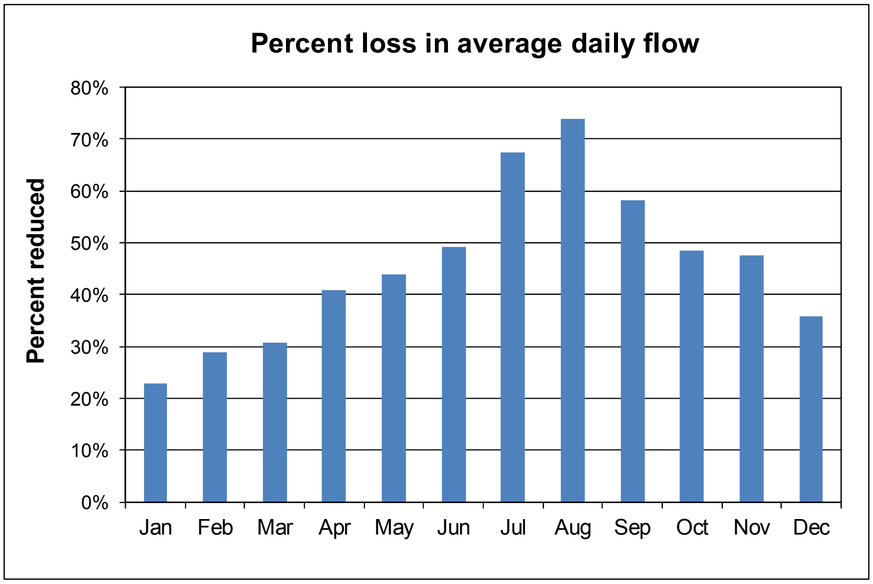

Figure 12. Estimated loss in daily average flow due to water management in the Shasta River as derived from data shown in Figure 11.

The construction of Dwinnell Dam and how water is managed with it has profoundly affected the volume and pattern of flow downstream of the dam and to a lesser degree in Parks Creek. Lake Shastina inflows are primarily derived from the Shasta River, but in addition, water from Parks Creek is diverted into the Shasta River upstream of Dwinnell Dam for storage in the lake under an existing MWCD water right (Vignola and Deas 2005).

Records of actual amount of water diverted from Parks Creek are not available, but the water right allows for up to 15,000 acre-feet per year between November 1 and June 1 (Vignola and Deas 2005). The Parks Creek diversion is effective when significant storm events occur or during normal or wetter years. When flows are available, MWCD typically diverts most of the flow in Parks Creek, leaving roughly 1.0 cfs in the stream. When flows available at the diversion exceed roughly 20 cfs, flows remaining in the stream increase to an estimated 4-6 cfs (Podlech and Black 2009).

Lake Shastina is designed to hold up to 50,000 acre-feet for storage. Vignola and Deas (2005) reported that since 1956, the capacity of the reservoir had reached its capacity approximately ten times or an average of twice every ten years.

Outflows from Lake Shastina are regulated either by the dam and canal for the MWCD water rights holders or are unregulated spill releases into the Shasta River. Spills occur when the reservoir is full during winter months or during heavy snowmelt in wet water years. Spill is rare and has only occurred 12 times since the dam was constructed (Willis and Deas 2009). When it does occur, flow volumes range from less than 100 cfs to over 1,000 cfs depending on inflow.

Podlech and Black (2009) described the distribution of water leaving the reservoir based on Dong et al. (1974) as follows: roughly 24,000 acre-feet are delivered annually via the MWCD canal system, approximately 30,000 acre-feet (or 50% of the total estimated Lake Shastina inflow) are lost to groundwater leakage and seepage, and about 6,200 acre-feet are lost to evaporation.

A small portion of the flow released by MWCD is allocated to water rights established prior to construction of Dwinnell Dam along the upper Shasta River downstream of the dam. This flow typically consists of 6-10 cfs being released to the upper Shasta River below the dam from early April through early September. Podlech and Black (2009) reported that there is often a period (September 1 – October 1) where the volume of water required to be delivered for these prior rights has been met. In such years, the releases for prior rights end early and flows into the upper Shasta River below the dam are considerably reduced. Flow releases of up to 3 cfs then continue until about mid-October for the upper portion of the reach (i.e., from Dwinnell Dam downstream for approximately 2 miles).

The majority of the flow managed by the MWCD, which is the largest irrigation district in the Shasta subbasin, enters the extensive diversion canal to be delivered downstream. The MWCD operates almost entirely from winter storage held in Lake Shastina (Podlech and Black 2009). The district operates 60+ miles of canals and lateral ditches to deliver water from the reservoir to downstream water rights owners during the irrigation season. The main canal is approximately 35 miles long.

Nichols (2008) concluded that the operations of Dwinnell Dam reduced the magnitude of average flow conditions of the Shasta River by up to 90% in some periods. He reported even greater reductions in the magnitude and frequency of high flows in the 6 mile reach segment immediately downstream of the dam (to Big Springs Creek).

The effects of these reduced flows on channel characteristics in this reach segment (above Big Springs Creek) have been significant. Nichols (2008) analyzed how the channel has changed over time. He concluded that lateral migration has been reduced, channel narrowing has occurred, the channel has been simplified, and meander wavelength has been reduced. In addition, Ricker (1997) reported that spawning gravels in this area have high concentrations of fine sediments, which reduce the quality of the spawning environment for salmon egg survival. All of these effects serve to reduce both the quantity and quality of this reach for salmon egg and juvenile production. My own personal observations of the reach in September 2011 showed that some areas contain very high amounts of fine sediments as a result of the lack of flushing flows.

Similar kinds of changes appear to have occurred in Parks Creek due to the MWCD diversion to Lake Shastina via the upper Shasta River. My observations of Parks Creek below the diversion found evidence of extensive degradation of channel characteristics to support salmon production. It is evident that the extremely poor habitat conditions in Parks Creek are due to various land and water use practices working in conjunction with the altered flow regime.

The effects of altered flow regimes on the Shasta River channel wane in the vicinity of Big Springs Creek. The large, steady flow contributions added by the creek, combined with a sharp reduction in channel slope, appear to strongly limit the effect of flow losses on channel pattern from Dwinnell Dam operations at that point (Nichols 2008).

Within the valley, numerous flow additions due to tributaries, springs, and agricultural return flows, combined with many flow diversions removing water from the main channel, create a complex flow regime with localized variations (Owens and Hecht 1998; Deas et al. 2003).

The flow regime in Big Springs Creek has also been changed by water management. The unimpaired flow out of Big Springs Creek is usually described to have been about 100 cfs year-round (Mack 1960; Null 2008; Figure 9). The upper reach of the creek, where one of the main springheads exists, was impounded around 1875, forming Big Springs Lake (Figure 13), to irrigate adjacent lands. Over time an extensive network of irrigation canals fed by the Big Springs complex was developed to support agricultural activities (Jeffres et al. 2009). Recent studies by the UC Davis Center for Watershed Sciences and Watercourse Engineering, Inc. describe the seasonal pattern of flows in the stream. The average flow during the non-irrigation season in 2008-09 was approximately 83 cfs.[17] During the irrigation season of 2008, average flow was 52 cfs with a low of 40 cfs. The flow reduction during irrigation was attributed to surface water diversions as well as to groundwater pumping in the vicinity (Jeffres et al. 2009).

Figure 13. Big Springs Lake.

4.1.4. Water Temperature Regime

Water temperature patterns in the Shasta River subbasin differ by location, depending on proximity to cold springs and land and water use activities in the vicinity. In the historic mainstem river, temperatures were largely driven by flow regimes, flow sources, and climate

[17] / The difference between the estimate of about 100 cfs for the historic unimpaired flow from Big Springs Creek (from Mack 1960) and the values between 80-90 cfs recorded in recent years after the irrigation season ends is attributed to natural long-term variation in spring flows according to Mike Deas (Watercourse Engineering, Inc., *personal communications*).

patterns (Null 2008). Riparian vegetation may have been less important on much of the mainstem river than it was in upper elevation tributaries, and there is uncertainty about the extent of the vegetation cover in the valley (Null 2008). The presence of aquatic vegetation in at least some springs was also an important factor in determining temperature (Nichols et al. 2010). The historic temperature patterns have been severely affected by reduced instream flows, diversion of spring-fed water sources, loss of riparian vegetation, agricultural return flows (tailwater returns), and instream grazing (Null 2008; Nichols et al. 2010).

It is helpful to the reader to note the range of temperatures of primary relevance to salmon biology. Generally, the preferred range for juvenile Chinook and coho is about 12-18°C (54-64°F) (Bjornn and Reiser 1991). Mortalities would be high in the range of 23-25°C (73-77°F) (Bjornn and Reiser 1991; McCullough 1999); higher temperatures would preclude their presence. High densities of food are thought to help ameliorate the effects elevated temperatures (Bisson et al. 1988). In the Klamath River system, juvenile coho actively seek refuge in cool water sites when water temperatures exceed about 19°C (Hillemeier et al. 2009).

While historic water temperature data for the Shasta River system are sporadic, the abundance of cold spring inflows suggests that large parts of the historic river maintained relatively cool temperatures in summer. Predictive modeling of historic temperature patterns using the historic flow regimes provides supporting evidence (Deas et al. 2004; Null 2008; Null et al. 2010). The NRC (2004), after reviewing the available information, concluded that the historic Shasta River may have somewhat cooled the mainstem Klamath River in the vicinity of the confluence of the two rivers.

In the upper parts of the historic Shasta River system, cold springs were well distributed, even in parts of Parks Creek, which should have kept those areas cool for salmon. The forested landscape in the upper elevation areas would have also helped to maintain suitable temperature patterns for both juvenile and adult salmonids. I expect that the thermal regime of these upper areas was well suited for the production of spring Chinook and coho, although the middle parts of Parks Creek and portions of the mainstem river upstream of Parks Creek may not been heavily used by pre-spawner Spring Chinook due to their need for cool water during summer holding. Thermal refuge areas in the proximity of cold springs were generally well distributed, however, which provided thermal refugia for fish.

Water temperature simulations using modeling techniques for parts of the Shasta River system have been made over the past decade (Deas et al. 2003; Deas et al. 2004; Null 2008; Null et al. 2010). For the historic river, modeled results by Null (2008) show that summer water temperatures remained well below 20°C (68°F) at GID (see Figure 7 for location), and below 25°C (77°F) at the river mouth (Figure 14). At GID, daily minimum water temperatures in summer remained below approximately 13°C, although daily maximum temperatures were substantially higher. The low daily minimum temperatures would have given some relief to fish following particularly warm days. Figure 14 shows that modeled temperatures at the site of Dwinnell Dam was approximately the same as that shown at GID.

Historically, the consistent, large volume (80-100 cfs) of cool water produced by Big Springs Creek would have been the primary driver of the thermal regime in the mainstem Shasta River downstream of its confluence. The spring sources for Big Springs Creek discharge at 10-12°C (50-54°F). It is now known that abundant aquatic vegetation in this stream, which provides shade cover to the water surface, reduces thermal loading, keeping temperatures relatively low. The Shasta River in the vicinity of Big Springs Creek, as well as the creek itself, would likely have been a major holding area during summer for adult spring Chinook in the historic river.

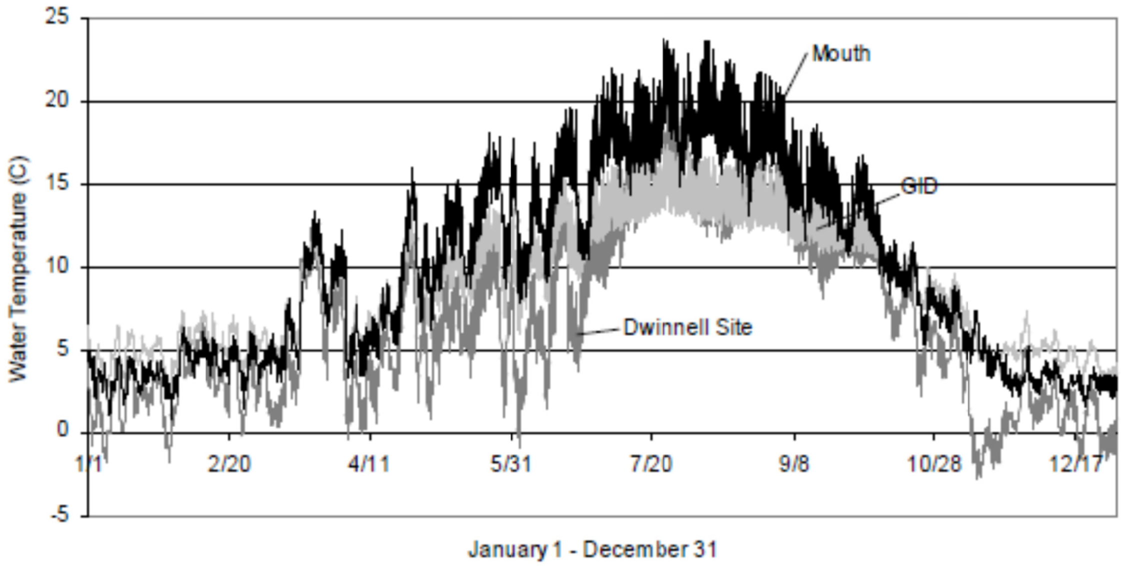

Figure 14. Modeled unimpaired water temperature for select Shasta River locations. Taken from Null (2008).

Watershed alterations throughout most the Shasta River subbasin brought with it major changes to water temperature patterns. Reduced flow levels associated with water management slowed transit times of water along the river, thereby increasing thermal loading. Loss of riparian vegetation along tributaries and the mainstem increased solar exposure in the streams. Tailwater returns have brought water elevated in temperature back to the streams after irrigating fields due to being warmed in ditches and fields, as well as in Lake Shastina (for water diverted from feature). These changes associated with land use, in addition to others, have increased water temperatures markedly (Null 2008).

Results of simulation modeling of current conditions in the subbasin illustrate the effects of management practices (Null 2008). Modeled water temperatures under current conditions are shown to be well above 20°C (68°F) at GID and sometimes attaining 30°C (86°F) at the river mouth (Figure 15). A description of water temperatures in the lower Shasta River given in CDFG (1997) is useful:

> "Water temperature has been a noted problem in the Shasta River since at least 1961 with levels reaching as high as 85°F between 1961 and 1970 (USDI 1985). High river temperatures generally exceeding 80°F primarily during June, July and August continue to plague the lower Shasta River. Low flows and high summer stream temperatures have been identified as the primary constraints to salmon and steelhead production (USDI 1985 and KRBFTF 1991). A water quality study of the Shasta River conducted by Ouzel Enterprises in 1990 documented temperatures in the

Shasta River as high as 89.6°F at the mouth and 82.4°F at the Highway 3 Bridge crossing (RM 12.5) (SVRCD 1991)."

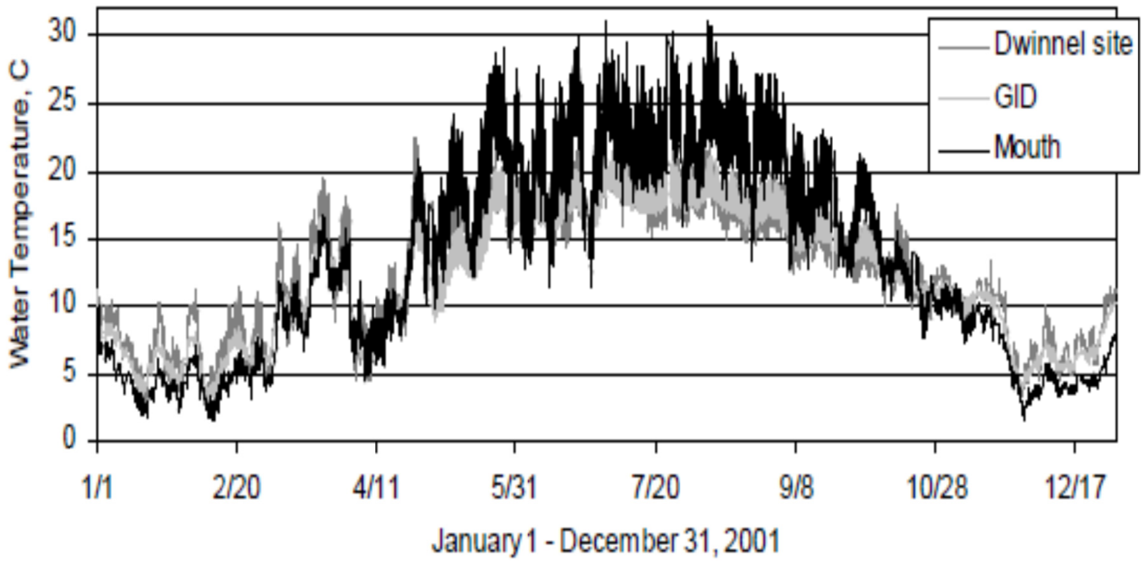

Figure 15. Modeled current conditions water temperature for select Shasta River locations. Taken from Null (2008).

The spatial distribution of water temperature in the Shasta River on one summer day in 2003 is seen in Figure 16 (NCRWQCB 2006). The figure provides a longitudinal profile of the surface water temperature in the river between Dwinnell Dam and the river mouth. Data used in the figure are from a FLIR aerial survey from an afternoon flight over the river on July 26, 2003.[18] The water temperature immediately downstream of Dwinnell Dam is seen to be between 21-23°C. Moving downstream there are three areas of temperature reduction associated with incoming springs. The effect of the inflow of Big Springs Creek (~ RM 34) is particularly noteworthy. Temperature is shown to be approximately 22°C immediately downstream of Big Springs Creek, then gradually dropping to a low of about 20°C in the vicinity of RM 30. This pattern of temperature in response to Big Springs Creek is due to warm water entering from the creek in the afternoon, but colder water from the inflow in the morning is evident further downstream. Gradually the effect of Big Springs Creek diminishes moving downstream until it is essentially gone at about RM 25. The profile shows that the water temperature pattern along the Shasta River is complex as a result of flow accretions of different types and daily warming and cooling patterns.

[18] FLIR stands for forward looking infra-red detection. A FLIR camera, mounted on an aircraft, uses imaging technology to sense and record infrared radiation, which is then translated to temperature.

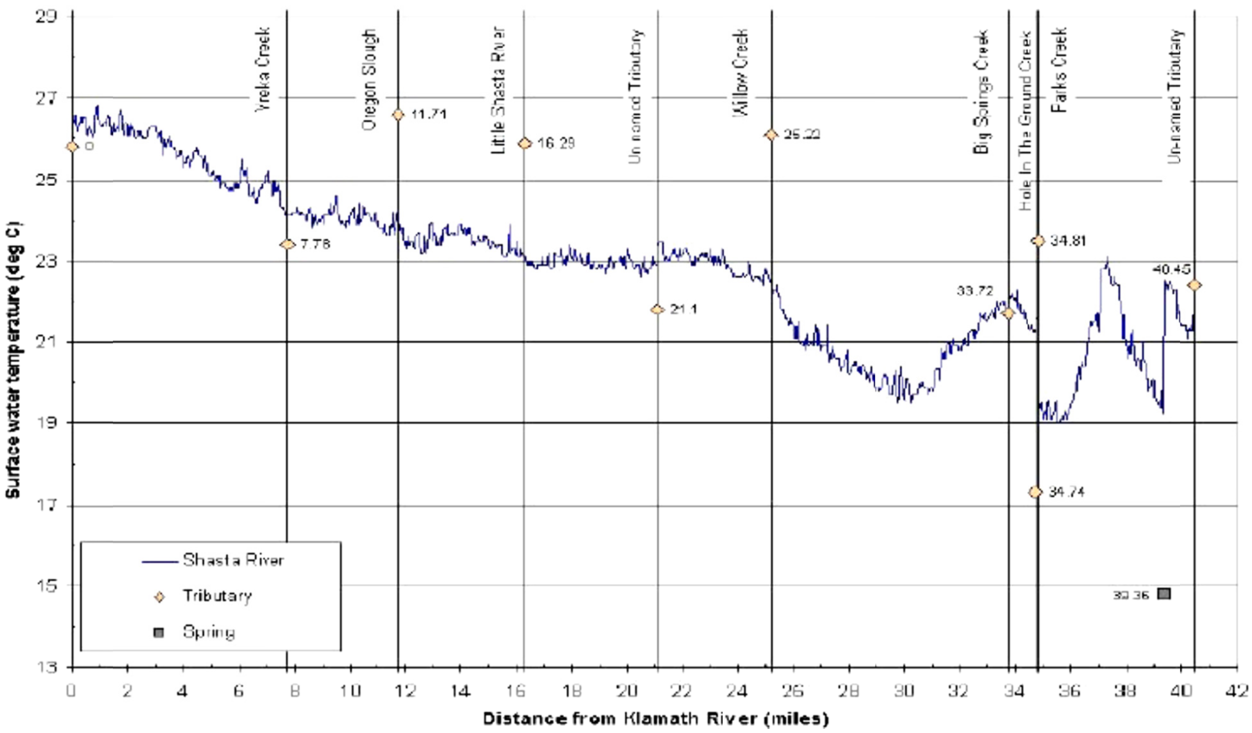

Figure 16. Spatial distribution of surface water temperature in the Shasta River on the afternoon of July 26, 2003. The data were obtained by a FLIR aerial survey. Taken from NCRWQCB (2006).

The historic role of Big Springs Creek in cooling the mainstem Shasta River has been much reduced over a major part of the past century. In the pre-altered subbasin, Big Springs Creek, which emerges at its sources at a consistent 10-12°C (50-54°F), was a key determinant of the thermal regime in the Shasta River. But as described above, the flow volume discharged to the Shasta River during the irrigation season is much less than its historic level. Perhaps more importantly, however, is how grazing within Big Springs Creek has affected thermal loading in the stream. Recent research by the UC Davis Center for Watershed Sciences and Watercourse Engineering, Inc. has helped to understand the temperature dynamics of Big Springs Creek with and without grazing occurring, and the effects on temperature in the mainstem Shasta River.

Besides being a major source of water diverted for agriculture, Big Springs Creek was subjected to intense grazing over the past century. All riparian vegetation along the stream was eliminated. Grazing also caused erosion of channel banks and the formation of a broad, shallow channel. These conditions resulted in high thermal loading of the stream (Jeffres et al. 2009). In addition, tailwater returns associated with flood irrigation practices on surrounding land exacerbated these conditions by bringing in warm water, causing further heating. Temperatures in excess of 30°C (86°F) were measured in tailwater returns to Big Springs Creek in May 2008. The effect of these conditions was that the creek delivered water to the Shasta River at times in excess of 25°C (77°F) (Null 2008; Nichols et al. 2010). Despite this, a short transit time of water through the creek from the springheads (approximately 2.3 miles) resulted in low nighttime temperatures in the creek being delivered to the Shasta River. This diurnal pattern of temperature would still have provided some benefit to fish even though daily maximum temperatures were quite high.

In 2008 and 2009, in conjunction with The Nature Conservancy (TNC) purchasing Big Springs Ranch, through which most of Big Springs Creek flows, restoration actions along Big Springs Creek were implemented. The actions consisted of fencing and cattle exclusion, although the latter was done in a way to allow some experimental treatment. Figures 17 and 18 illustrate the effects of cattle grazing on the abundance of aquatic macrophytes growing in the stream.

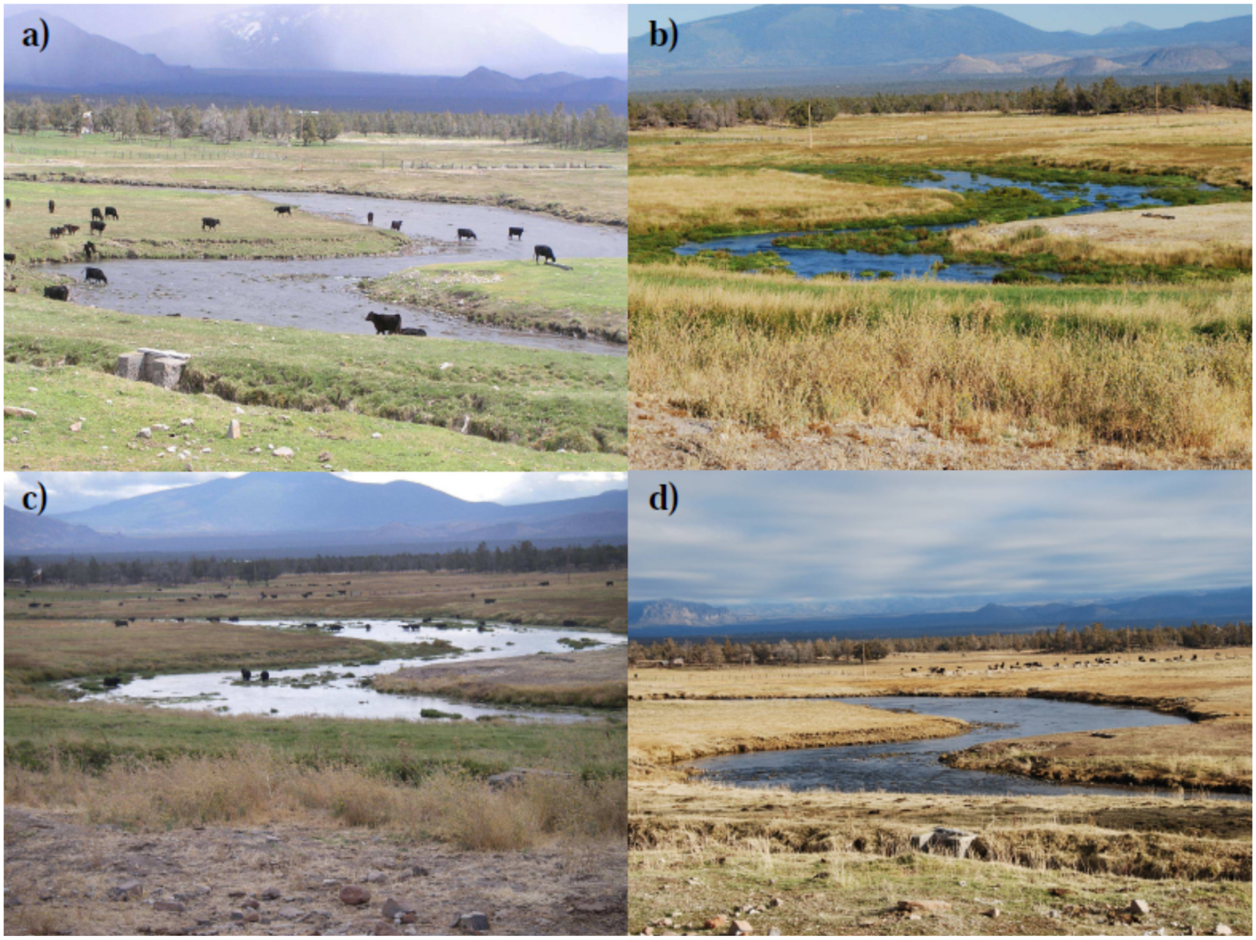

Figure 17. Photo series documenting temporal changes in Big Springs Creek aquatic macrophyte growth. Big Springs Creek during (a) initial conditions after instream cattle grazing in March 2008, (b) after five months of no grazing in September 2008, (c) three weeks after cattle were reintroduced, and (d) after four months of instream cattle grazing. Taken from Jeffres et al. (2009).

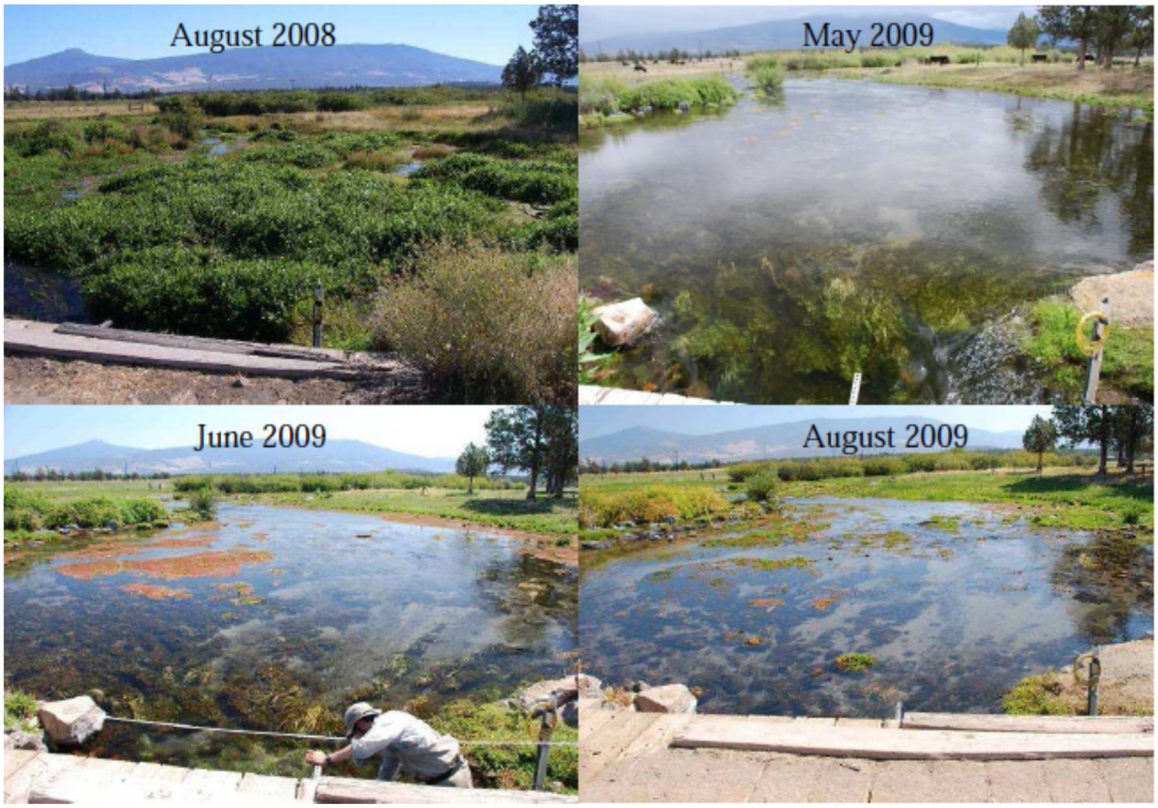

Figure 18. Time series photos showing reduction in aquatic vegetation downstream of Big Springs Lake as a result of cattle grazing in the channel. Instream cattle grazing occurred from April 1, 2009 through July 21, 2009, which removed much of the aquatic vegetation from the creek. Taken from Nichols et al. (2010).

The results of studies show that grazing within Big Springs Creek was having an enormous effect on aquatic vegetation, which in turn was strongly affecting thermal loading in the stream. The aquatic vegetation was found to reduce solar loading by providing shade to the water surface. It also reduced transit times of water through the stream by increasing flow velocities. The lush growth of aquatic macrophytes within the stream channel, growing in large, dense patches, deepened stream flow and created high velocity corridors between the patches. These conditions reduced the transit time of water between the spring inflows and the stream mouth (Figure 19). The combination of these conditions resulted in significantly less warming of the stream and the delivery of appreciably cooler water to the Shasta River (Nichols et al. 2010). The beneficial effect in the mainstem river is believed to have extended downstream many kilometers in 2009.

Figure 19. Photos of Big Springs Creek in September 2011. Flow velocities within the main unvegetated flow corridors were relatively fast.

The preceding discussion on temperature regimes mentioned the influence that flow quantity can have on Shasta River temperature. It is useful here to elaborate on this for the sake of considering action priorities later in the report. Both Deas et al. (2004) and Null (2008) examined this matter in some depth. I highlight a few of their conclusions here.

Figure 20, taken from Deas et al. (2004), illustrates the relationship between flow and water temperature in hypothetical model simulations where flow is assumed to be either 50 or 100 cfs throughout the Shasta River from Dwinnell Dam to the Klamath River. The simulations were modeled for climate conditions that existed in the subbasin on August 28, 2001. The simulations are necessarily simplified as they do not account for the complex water management pattern of the river, nor do they consider accretion and depletion along the river. Still, they are useful to illustrate the influence of the amount of river flow on water temperature. The water begins to heat rapidly as it travels downstream of Dwinnell Dam. When the flow amount is increased to 100 cfs, the rate of heating is notably less than with a flow of 50 cfs. In both cases, the rate of heating decreases as the river approaches equilibrium temperature, which for the day modeled was approximately 19.5°C (67.1°F).[19] The temperature achieved at the river mouth at 100 cfs is less because of a shorter transit time between the dam and the mouth (greater volume increases water velocity), and there is greater thermal mass to maintain cooler temperatures. In addition, daily maximum and minimum temperatures are affected by flow rates. Larger volumes of water heat and cool more slowly on a daily basis, leading to a moderated diurnal range compared to smaller volumes of water.

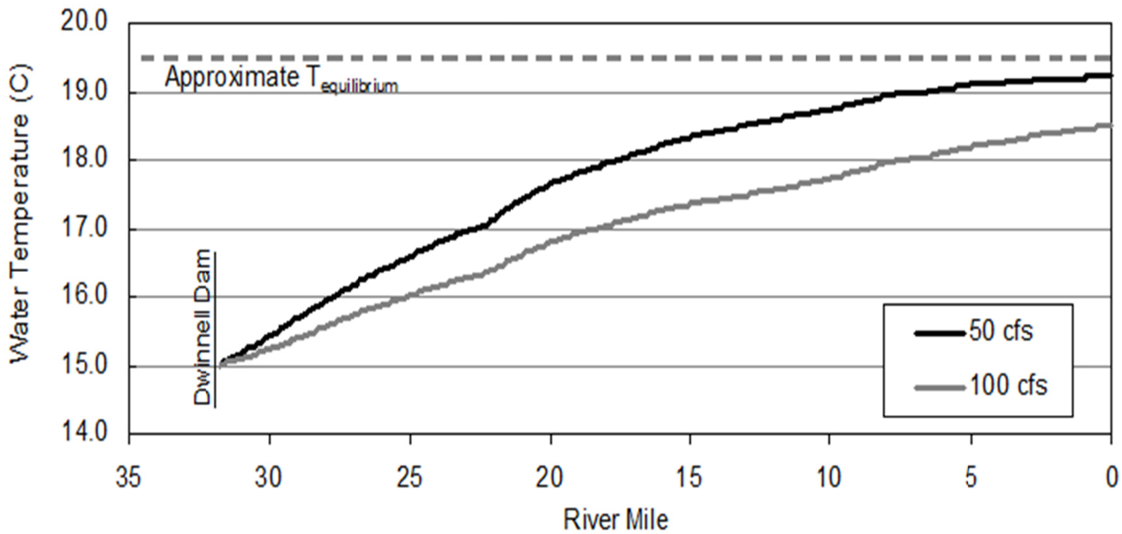

Figure 20. Simulated average daily water temperature under steady flow conditions (50 and 100 cfs) in the Shasta River from Dwinnell Dam to the Klamath River with meteorological conditions as they existed on August 28, 2001. Taken from Deas et al. (2004). Note: the river mile at Dwinnell Dam is shown to be about 32.5; this report uses a RM value of about 40 to be consistent with information reported in other documents.

Null (2008) used simulation modeling to investigate the potential beneficial effects on water temperature in the mainstem Shasta River by fully restoring Big Springs Creek. Null assumed that with full restoration, the flow in Big Springs Creek would produce a summer flow of 104 cfs and a winter flow of 124 cfs. The amount of flow increase over current conditions would be between 30-50 cfs depending on season. With restoration, Null assumed the creek would be sufficiently shaded and channelized to deliver water at nearly the spring inflow temperatures (presumably consistent with how Jeffres et al. 2009 described the elements of a full restoration scenario). Figure 21 displays results for the month of August 2001; the year 2001 was a relatively dry year. Water temperatures in the Shasta River are shown to be significantly reduced

[19] / Equilibrium temperature, as defined by Deas et al. (2004), is the water temperature that would be reached if all meteorological conditions were constant over the time and space being modeled, and water was allowed to reach a steady temperature in response to those conditions.

with full restoration of Big Springs Creek because large contributions of cool water are added and increased flow increases thermal mass (which heats and cools more slowly on a daily basis).

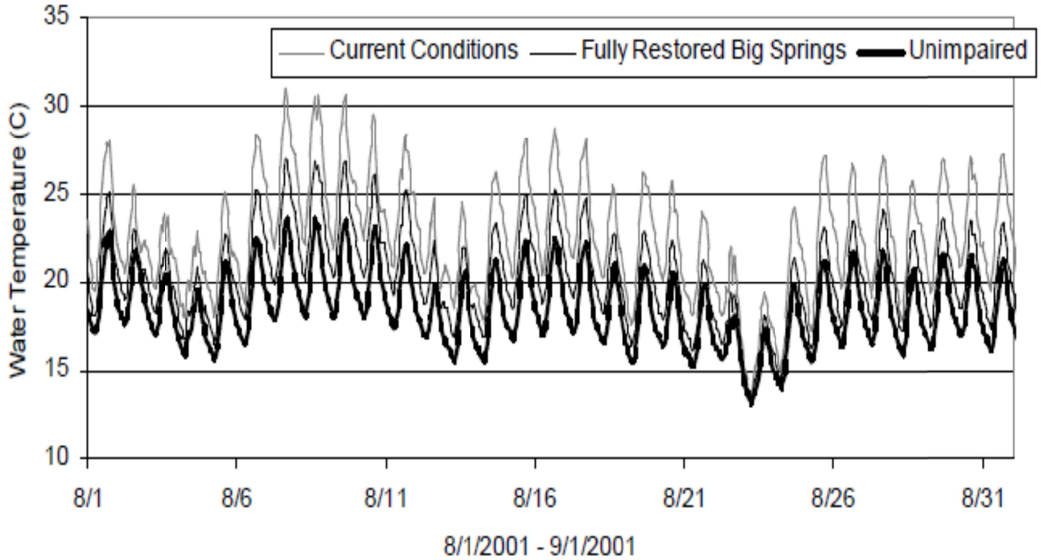

Figure 21. Simulated water temperature at the mouth of the Shasta River under current conditions, fully restored Big Springs Creek, and unimpaired conditions (unimpaired for the entire Shasta subbasin). Taken from Null (2008).

4.1.5. Shasta River Channel Profile and Related Characteristics

The profile of a river, showing how channel slope changes over the length of the river, is helpful to identify how a river might be used by salmon in different life stages. The profile of the Shasta River is particularly insightful for this purpose (Figure 22.). Figure 22 (top) shows the elevation of the mainstem channel from the river mouth to about RM 56. Figure 22 (bottom) shows channel slope expressed as a percentage over the same distance. Nichols (2008) characterized the profile as exhibiting four morphologically distinct segments, which are clearly seen in Figure 22 (bottom). A steeper headwater section with channel slopes exceeding 2% occurs upstream of about RM 52, which transitions to a section with slopes between about 0.3% to 2% down to about RM 32. A drop in channel slope at this point occurs roughly in the vicinity of Big Springs Creek, where the slope is generally 0.1% or less between there and the start of the gorge at RM 8. The slope increases again through the gorge where it is about 1%.

These four distinct segments differed historically with respect to the size of their substrates, as they still do today. Substrate sizes reflect the patterns in channel slope, flow regime, and geology between the upper part of the watershed to the lower part (Nichols 2008). The substrate of reaches upstream of Big Springs Creek (RM 34) is composed primarily of gravel and cobble mixed with sand sized particles (not considering the reach under Dwinnell Reservoir)(Nichols 2008; McBain and Trush et al. 2010). The long, flat segment of channel between about Big Springs Creek and the gorge is dominated by smaller sediments—mainly silts, sands, and small gravels. Substrate in the gorge is dominated by gravel and cobble. It is noted that historically the reach now inundated by Dwinnell Reservoir was probably dominated by silts and sands, assuming the presence of marsh habitat (see Figure 7). Still, there might have been small reaches within the area of marshes that contained gravels, which often is the case in these kinds of areas. The bottom substrate beneath Dwinnell Reservoir today would be entirely silt and sand, except on the delta at the head end of the reservoir where gravels also exist.

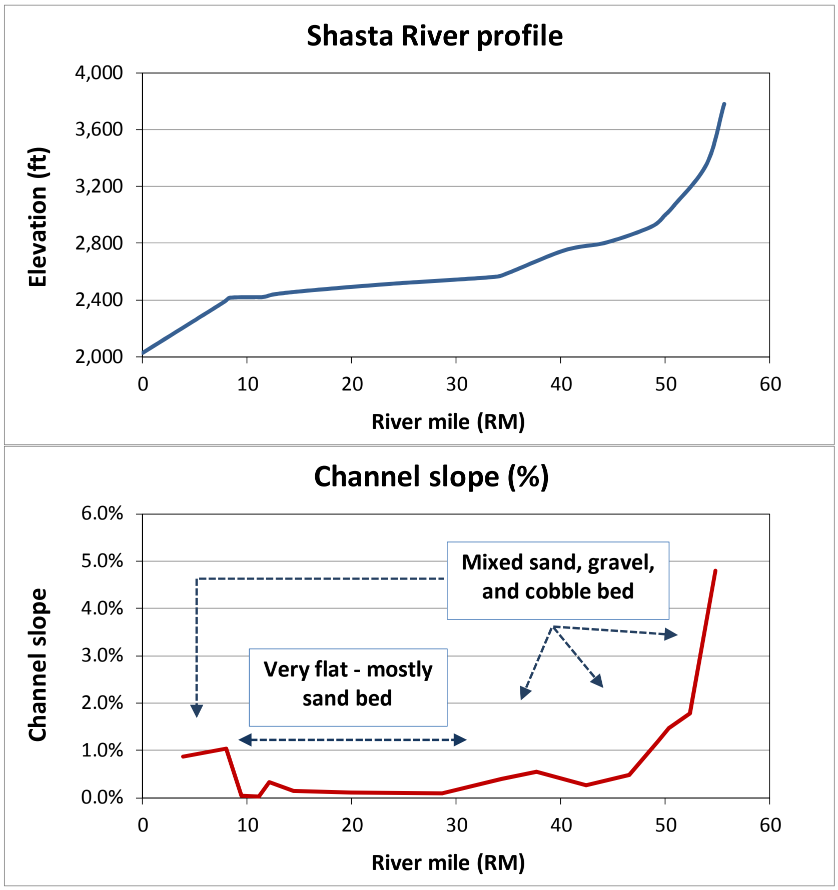

Figure 22. Channel profile of the Shasta River (top) and channel slope values expressed as a percent (bottom). The bottom graph also shows the most likely substrate composition along the river based on channel slope (also see text for additional documentation).

The pattern for channel slope and substrate sizes can be used to identify the likely patterns of how salmon generally used the historic river system in different life stages (Figure 23). These associations will be used to draw species-specific conclusions in Section 4.2.2. Here, I use this information to draw some very general conclusions applicable to all of the Shasta salmon populations. It is quite certain that the major historic spawning areas in the mainstem Shasta River occurred in two sections, one being in the gorge reach downstream of about RM 8 and the other being upstream of the slope break that occurred near RM 34 corresponding to the confluence of the river with Big Springs Creek. Some spawning would have occurred in patches of suitable gravels between the gorge and Big Springs Creek but it would have been relatively minor compared to how the other areas were used for this life stage. The long section between the gorge and Big Springs Creek would have primarily been used for juvenile rearing and as a migration corridor for adults and juveniles. The greatest amount of spawning habitat would have occurred upstream of Big Springs Creek. Coho, for example, could have used the upper parts of the river to where the gradient reached at least 4%. The upstream limit of spawning by spring Chinook was likely downstream of the limit to coho use, probably dictated more by the amount of flow available.

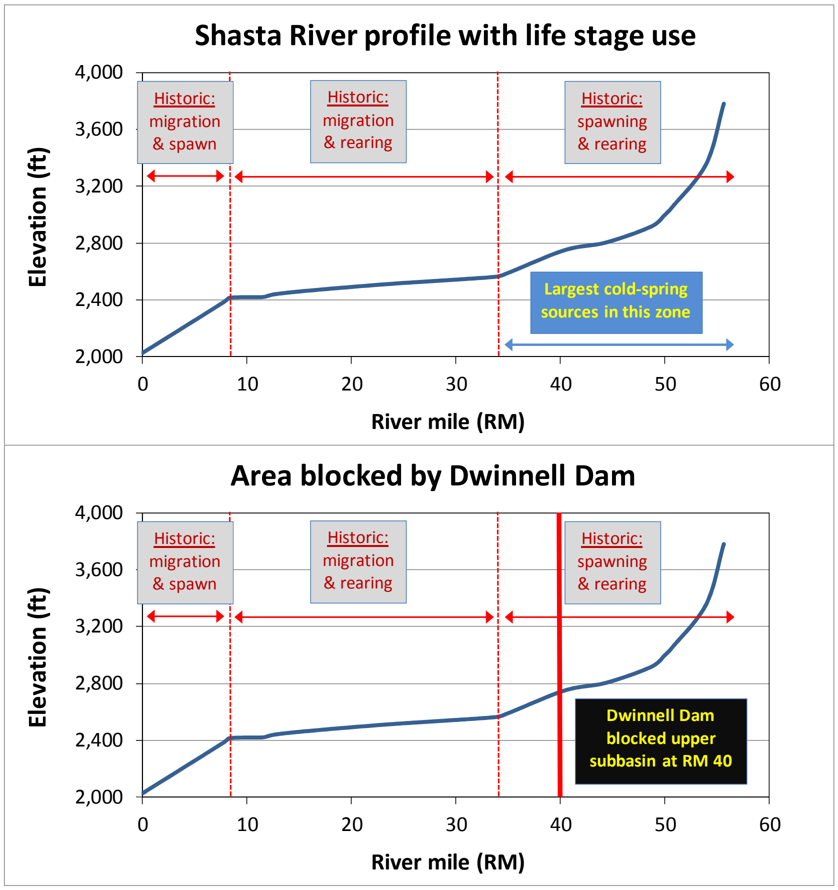

Figure 23. Identification of life history functions to salmon by the main Shasta River by location along the river. Reference is also made of the main spring flow sources and the location of Dwinnell Dam.

Figure 23 also identifies two other spatial references that are key aspects for the diagnosis. The area of the greatest quantity of spring inflow—as well as the highest density of springheads that produce this flow—exists upstream of the slope break that occurs in the vicinity of Big Springs Creek (about RM 34). Although the greatest flow of any single spring complex is the one associated with Big Springs Creek, major springs also occur well upstream of there, feeding, for example, Beaughton and Boles creeks (RM 49 and 50, respectively); smaller springs also occur upstream of there.

The second reference point of relevance to this report seen in Figure 23 is the location of Dwinnell Dam (RM 40). It is evident that the dam blocked access to a large portion of the historic spawning grounds, as well as to areas having significant cold water inflows from springs.

It should be noted that while Figures 22 and 23 are focused on the mainstem Shasta River only, other significant spawning and rearing habitats occurred historically in tributaries. Important spawning areas for coho, for example, would likely have existed in Yreka Creek, Little Shasta River, Willow Creek, Parks Creek, Carrick Creek, Beaughton Creek, and Boles Creek. Major portions of these streams are now entirely or partially blocked by barriers. Of these, Carrick, Beaughton, and Boles creeks are blocked by Dwinnell Dam. Time has not allowed me to do a more in-depth analysis of these streams with respect to how they were likely used by salmon. A short summary of channel characteristics of Big Springs Creek is provided in the following section.

4.1.6. Big Springs Creek Channel Characteristics

A more complete description of the channel characteristics of Big Springs Creek is needed due to the stream's important role in salmon production in the subbasin. The following is summarized primarily from Nichols et al. (2010), though I also provide my own observations based on two limited field visits.

Big Springs Creek emanates from several discrete springs along its path and from Big Springs Lake at the upper end of the creek. The lake was initially formed in 1875 as an impoundment for irrigation purposes. The distance from the downstream end of the lake to the stream mouth is about 2.7 miles. Currently the lower 1.9 miles of the stream are used by salmon spawners (Chesney and Knechtle 2010).

Recent studies in Big Springs Creek clearly demonstrate that aquatic vegetation acts as a control on physical, chemical, and biological processes in the stream. Intensive grazing practices in the past kept the standing crop of aquatic vegetation in the stream to a small fraction of that produced in the absence of grazing. Without grazing, the stable flow regime of the creek combined with a high naturally occurring nutrient load and low channel slope promotes extremely rapid growth of submerged and emergent vegetation. Dense, large patches of the vegetation develop in the spring and summer, followed by senescence in the late fall and winter when large amounts of the plant material die back (Nichols et al. 2010).

The growth and senescence cycles of the aquatic vegetation in the absence of grazing strongly affect local channel hydraulic conditions, causing seasonal changes in stream depth, wetted cross-sectional area, and water velocity. As a result, the characteristics of instream habitats differ substantially between seasons.

During spring and summer, the rapid growth of the vegetation patches forces the development of flow corridors between the patches. As the biomass and density of the patches grow, the stage height of the stream flow increases (due to a reduction in the effective cross sectional area through which the water flows). The result is that water velocities are substantially increased as more of the flow is routed through the progressively narrower unvegetated corridors. As described in a prior section, these conditions provide shade to water moving through the vegetated patches, reduced water surface area exposed to solar radiation, and faster transit time of water between the spring sources and the stream mouth. These effects reduce water temperature in the stream compared to conditions when grazing occurs.

In late fall and winter there is a substantial die-off of vegetation, though patches of submerged vegetation remain. The effect of this seasonal large reduction in vegetation is that the cross-sectional area of the channel open to unobstructed flow is increased significantly; the flow pattern is once again spread over the entire channel width. I observed the conditions in December 2011 up close by snorkeling. Flow velocities in the stream during my visit were less than what I had seen during a field trip in September 2011. The stream flow across the channel width appeared to be very uniform in velocity. Flow velocities were generally faster than those preferred by juvenile coho. Little habitat structure existed to provide refuge for overwintering juvenile coho.[20] The stream at that time was relatively shallow and provided very little habitat diversity. My impression was that it had characteristics more like a spawning channel than a stream affording a diversity of winter rearing habitats.

The seasonal changes to the stream due to the vegetation growth and senescence cycles appear to strongly affect patterns of sediment deposition and erosion within the stream channel. Nichols et al. (2010) noted that the hydraulic action of these changes promotes the scouring of fine sediments from the gravels. This may help to clean the gravels used by spawning salmon.

Nichols et al. (2010) hypothesized how Big Springs Creek will change as the restoration practices that have already been implemented continue to mature. In the absence of grazing disturbances, macrophyte root masses and more resilient stem materials will likely remain in place throughout the year, allowing the capture of mobile sediments and organic material produced by the fall and winter senescence. This process over time would be expected to create a peat/marsh habitat dominated by emergent vegetation along the channel margins and low-velocity channel areas adjacent to the main flow paths. Such an outcome would be consistent with the way the initial public land surveys in 1856 described Big Springs Creek. The stream was described as a wide marsh with a several meters wide freshwater creek flowing through it. Also, I would note that the flow velocities in 1856 were likely faster than what has recently been observed in the creek due to the higher flows believed to have existed at various times in the past in conjunction with well formed, relatively narrow flow paths through the stream corridor.

In my view, the picture that emerges of the historic creek is of a stream that served primarily as a stable spawning environment for both Chinook and coho. Due to its relatively swift velocities, juveniles rearing there would primarily have been Chinook and steelhead, which generally use faster flows than coho (Lestelle 2007). I am not saying that juvenile coho did not use it for rearing—I believe it served that purpose, but not to the same extent that the other species reared there. I think the stream's greatest benefits, however, were to spawning and to both thermal influence and flow stabilization to the extensive habitats downstream through the valley.

4.2. Life History Patterns and Spatial Use of the River

This section summarizes information to assess how the Shasta River was used historically and in its current state by salmon populations.

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[20] / Juvenile coho typically prefer very low velocity habitats during winter.

4.2.1. General Life History Patterns in Freshwater

Descriptions of the relevant aspects of the freshwater life history of Chinook and coho are summarized below.

4.2.1.1. Chinook Salmon

Life history diversity of Chinook is greater than for the other Pacific salmon (Healey 1991). When both spring and fall Chinook are present in a single watershed, the diversity of life histories is especially evident. While there is uncertainty about some aspects of the life history characteristics of Shasta River spring Chinook, enough is known about the river and spring Chinook in general to formulate reasonable hypotheses. Characteristics of Shasta River fall Chinook are sufficiently known for purposes of this analysis.

The spring and fall runs of Chinook in a river system are distinguished as separate genetic races due to their distinctive run timing patterns. Run timing is a heritable trait (Ricker 1972; Quinn 2005). Spring run Chinook typically enter freshwater during months in spring and early summer, while fall run Chinook enter in late summer and fall (Nicholas and Hankin 1988; Moyle 2002). Snyder (1931) said that spring Chinook began moving upstream in the Klamath River in the latter part of February and were almost entirely in the river by the last of May. In contrast, the fall run begins entering the Klamath River in July, peaks in late August to early September, and then tails off until December (Snyder 1931; Barnhart 1994). The river entry timing of the historic Shasta River spring Chinook was probably consistent with the timing pattern of the Klamath River spring run in general. The Shasta fall run might be on the early side of the general pattern seen for the Klamath fall Chinook on the whole (Toz Soto, *personal communications*).

Snyder (1931), citing anecdotal information, said that spring Chinook arrived in the region of Happy Camp in May or June, and in the Shasta River in June and early July. Typically, spring Chinook move well up into a river during the snow runoff pulse on the hydrograph (Beechie et al. 2006; Skokomish Indian Tribe and WDFW 2010). In the Shasta River, the snowmelt pulse generally occurs in May and June (Figure 9). The hydrograph suggests that spring Chinook might have moved into the Shasta River primarily in May and June.

CDFG (1997) described the entry timing of adult fall Chinook into the Shasta River as beginning in early September and continuing into November based on weir operation near the river mouth. Chesney (2009) found that the peak movement into the Shasta River occurred during the last week in September and the first week in October.

The spatial distribution of the spawning fish of the two races in the Shasta River was not documented in years when both were still present. Nicholas and Hankin (1988), in reviewing life history characteristics of Chinook in rivers along the Oregon Coast, including in the Rogue River which has many similarities to the Klamath River, said this about the spatial distributions of the two races:

> "We surmise that fall- and spring-run races endemic to a river system must have relied primarily on spatial rather than on temporal segregation of spawning populations to maintain their respective population identities."

In a single mainstem river where the two races of Chinook co-exist, the earlier timed spring run will migrate to the upper reaches to spawn, while the later fall run will generally spawn in the lower reaches. This is the general pattern on every river that I am familiar with in the Pacific Northwest where the races co-exist. But the spatial distribution of spawning by the two races can and does overlap in some rivers, such as in rivers along the Olympic Coast in Washington and in the Klamath's own Salmon River (Toz Soto, *personal communication*).[21] In these cases, however, spatial overlap is not extensive. Barnhart (1994) stated that spring and fall Chinook in the Klamath-Trinity Basin in general show some spatial overlap in spawning. In the Trinity River, there can be substantial overlap but it is the result of hatchery operations in conjunction with a dam blocking adult migration.

The spatial distributions of the spawning aggregates of the two races appear to be largely related to water temperature regimes. Since spring Chinook enter their natal spawning river before peak water temperatures occur in summer, they require cool water holding areas to survive the summer prior to spawning. This need is met by the fish generally moving into the upper parts of a river where temperatures are cooler. In the historic Shasta River, the upper river was cooler due to the abundance of spring sources, higher elevation, and riparian corridors that probably had high densities of trees to shade the streams (discussed elsewhere in this report). In contrast, fall run fish usually migrate upstream after water temperatures have abated and are declining; therefore their spawning distribution is not associated with where cool water is located in summer.

Another way that water temperature operates to maintain some measure of spatial segregation is in regulating the time of spawning. The onset of Chinook spawning is triggered in part when temperatures drop to certain levels, though the exact temperature when this happens can be stock specific, being related to temperature unit accumulation within the incubation environment and optimal time for fry emergence (Miller and Brannon 1982). Hence, time of spawning is also a genetic adaptation for individual stocks related to several factors. For these reasons, spawning timing is usually earlier for the spring run than for the fall run within the same river due to the natural distribution of temperatures in the river (Lestelle, *in preparation*).

Barnhart (1994) stated that extant spring Chinook in the Klamath-Trinity Basin spawn a few weeks earlier than fall Chinook although there is some overlap in timing. He characterized spawning timing of spring Chinook as beginning in September and peaking in October. In the Rogue River Basin, spring Chinook spawn primarily during September and October, whereas fall run fish spawn during October through December (Nicholas and Hankin 1988). Chesney and Knechtle (2010) showed that most spawning by fall Chinook in the vicinity of Big Springs Creek and Parks Creek occurs in October, generally peaking in the second half of the month. I would note that if the spawning of fall Chinook in the historic river was the same as that observed

[21] Toz Soto, biologist with the Karuk Tribe, has observed movement and holding behaviors of fish believed to be spring and fall Chinook within the same reach of the Salmon River. His observations suggest that members of one race may avoid one another, suggesting some degree of discriminating separation of the races.

today, then spring Chinook peak spawning timing may have occurred in late September or early October in the area of cold springs.

Time of fry emergence by fall Chinook in the Shasta River in recent years occurs primarily in March and early April, based on fry trapping results (Chesney 2002). It is likely that emergence timing was similar for fall Chinook in the historic river. This timing pattern suggests that emergence may have generally been several weeks earlier for spring Chinook but it may have overlapped with that of fall Chinook. There is much uncertainty, however, when spring Chinook fry emerged because of the effect of the water temperatures associated with spring inflows. It is possible that emergence was much more advanced than that of the fall run fish that spawned in the Shasta canyon. Water temperatures in the vicinity of the major springs would have generally accelerated incubation timing compared to areas in the canyon.

Three juvenile life history patterns have been identified for Chinook in the Klamath Basin (KRBFTF 1991; Barnhart 1994), as defined below:[22]

- Type I – juvenile outmigration (seaward movement) occurs in spring and early summer within a few months of fry emergence from the spawning gravels;
- Type II – juveniles rear through spring and summer within the natal stream, then outmigrate to the ocean in the fall; and
- Type III – juveniles rear within freshwater for approximately one year after fry emergence and outmigrate as yearlings to the ocean.[23]

Most Klamath River juvenile Chinook are believed to have a Type I juvenile life history pattern (Sullivan 1989 cited in Barnhart 1994), but this is based on data after major alterations occurred in the basin and apparently on samples of fall Chinook. Sullivan (1989) found the Scott and Salmon rivers produced higher frequencies of Type II fish than seen elsewhere in the basin. Small numbers of Type III fish were also present in the basin. Toz Soto suggests that Salmon River spring Chinook may tend to have a Type II life history (personal communications); this may be due to cold incubation temperatures, relatively cool summer rearing temperatures, and relatively limited food supplies.

A relatively long-term data set on juvenile Chinook life history patterns exists for the Rogue River—a river system that has many similarities to the Klamath system. Both spring and fall Chinook are abundant in the Rogue Basin. The Rogue database includes results of analyses of size at ocean entrance for both spring and fall Chinook as well as time of ocean entrance. The Rogue data show that the average length of juveniles that survived to return as adults was about 10 to 11 cm over ten brood years for both races (Nicholas and Hankin 1988). The peak period of ocean entrance for both races was in mid-August to early September (for fish that survived to return as adults).

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[22] / It is noted for readers not familiar with Barnhart's classification system that Healey (1991) referred to fish exhibiting the Type I and II patterns as "ocean type" and Type III as "stream type." Barnhart, in contrast, referred to the Type II pattern as "stream type." Use of the terms "ocean type" and "stream type" in this document is avoided for this reason.

[23] / The Type III pattern described for Chinook is identical to the typical juvenile life history exhibited by coho in the Pacific Northwest and California. From the time of egg fertilization, these fish are roughly 18 months old at the time of seaward migration and they are commonly called yearlings at that time.

The Rogue data, as well as data for other coastal populations in Oregon (Nicholas and Hankin 1988) and Washington (Lichatowich and Mobrand 1995; Lestelle et al. 2005), show that most juvenile spring Chinook produced in coastal rivers migrate to the ocean in summer or fall of their first year of life. A common misconception about spring Chinook in general is that they tend to be yearlings (Type III) regardless of what river they are produced in. This misconception has come about because Healey (1991) generally classified spring Chinook as having a yearling outmigration (although he noted "apparent exceptions" such as Rogue fish). Also, the large runs of spring Chinook in the Columbia and Fraser rivers are produced mainly in the interior regions, and those populations are dominated by the yearling life history type.[24] Many biologists have mistakenly generally assumed that the dominant life histories seen in the Columbia and Fraser rivers exist elsewhere.

The dominate juvenile life history type of spring Chinook in the historic Shasta River was likely Type I with a small proportion of Type II fish and even fewer Type III fish. Emergent fry from the upper Shasta River spawning areas, including from Big Springs Creek, would have become widely dispersed between their upper spawning sites and the lower river. Growth rates of fish during spring and summer were likely a function of where the fish were located. Fry residing in the most upstream areas, where temperatures were probably cooler in early spring compared to those in the valley, would have grown more slowly than fish in Big Springs Creek and downstream of there. The rich, abundant food sources in and near the main springs and in the valley would have facilitated very rapid growth. Also, there is some indication that spring Chinook may tend to linger nearer their natal areas compared to fall Chinook fry—the latter often show some degree of a strong initial fry migration (Healey 1991; Skokomish Tribe and WDFW 2010). The differences between the two races may occur when the two races co-exist, thereby providing for some degree of spatial segregation of rearing areas.

The majority of the spring Chinook juveniles likely entered the Klamath in late spring and summer due to their relatively large size. It is likely that their primary time of ocean entrance was no later than Rogue River fish (late summer, early fall) because of their larger size that the Shasta River would have produced. Their size may have facilitated an earlier ocean entrance. Those juveniles that held in the upper parts of the Shasta River through the summer probably moved seaward mostly as Type II fish. Some might have left as Type III fish. The historic timing and distribution of spring Chinook in the Shasta River suggests that if these fish were present in the river today (such as through a re-introduction program), then water temperature would be a strong factor in their survival.

The large majority of fall Chinook juveniles emigrate out of the Shasta River in March and April as young fry (Chesney 2002; Chesney and Yokel 2003). Smaller numbers continue to emigrate through June. The initial large outmigration consists mainly of newly emerged fry. As the migration progresses, the size of the emigrants becomes larger. The last part of the migration consists of relatively large fish, often averaging about 8 cm, but some are approximately 10 cm. These patterns show that the juvenile life history pattern of Chinook that are currently produced in the Shasta River primarily exit the stream before water temperatures pose much of a threat.

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[24] / The spring Chinook in the interior region of these rivers typically spawn at relatively high elevation in streams that are very cold in winter. These conditions prolong incubation time and tend to slow initial growth rates of fry.

4.2.1.2. Coho Salmon

Across their geographic ranges, there is generally much less diversity in life history for coho than is demonstrated by Chinook (Sandercock 1991; Healey 1991). But as more information continues to be gathered on coho, it is apparent that the species exhibits a much greater amount of diversity in life history than once was commonly believed (Lestelle 2007).

With respect to Shasta River coho, evidence suggests that this population both historically and to some degree still today manifests a greater range of life history than seen in most other coho populations. The river can produce exceptionally large young-of-the-year juveniles by the end of their first spring, in addition to the typical yearling smolts that emigrate in the spring of their second year of life (Bill Chesney, *personal communications*). The possible significance of this pattern is discussed further at the end of this section. The diversity provided by this pattern is no doubt directly linked to the spring-fed inflows to the river. To what extent these life histories are genetically influenced is not known.

Adult coho return to the Klamath River from the ocean from mid-September through December (Barnhart 1994). There is no reason to believe the river entry timing of Shasta River coho is any different. The majority of adult coho in the Klamath River are believed to be three-year olds.

Adult coho migrate into the lower Shasta River during the months of October through December, based on video weir daily estimates (CDFG, unpublished). Peak migration generally appears to occur in the second half of November.

Coho spawn in the Klamath system during the months of November through January. Peak spawning appears to usually occur during early to mid-December (Toz Soto, *personal communications*), which is very similar to the timing of wild coho on the Oregon and Washington coasts (Sandercock 1991). It is noted, however, that low abundances of Klamath River wild coho make determination of spawning timing patterns difficult to know with certainty. Spawning timing in the Shasta River is probably comparable to timing in other upper Klamath tributaries.

Coho spawn mainly in small streams or in side channels to larger rivers, a pattern seen across the species range (Burner 1951; Sandercock 1991; Moyle 2002). They sometimes spawn along the margins of large rivers, but normally not in large numbers. The size of the Shasta River would suggest that historically coho could have spawned in all reaches of the river and its tributaries where the gradient and substrate were suitable.

The primary spawning grounds for coho in the historic Shasta River would have been in all of its tributaries containing sufficient flow and in the mainstem river upstream of approximately Big Springs Creek. Spawning in the mainstem river would have extended upstream of Dale Creek. By comparison, spawning through the main valley was probably relatively minor due to its low gradient, fine grained substrate, and likely lack of upwelling spring sites within the channel. Some spawning would have occurred in the canyon but its relatively large channel size and large cobble were not optimal to accommodate large numbers of fish.

Several decades ago, coho were usually thought of as only being associated with relatively low gradient stream reaches where pool habitat was abundant. This view of coho life history developed because juvenile coho in summer are most often found in low gradient habitats and especially in pools. It is now known that coho will also spawn heavily in relatively high gradient channels where good rearing habitat for their progeny is virtually absent (e.g., Lestelle et al. 1993). Spawning streams can range in slope up to about 4% or higher. When spawning streams lack suitable fry colonization and rearing habitat, the fry can disperse downstream considerable distances to locate suitable conditions. Coho will spawn in extremely low gradient reaches if there are sites of upwelling caused by spring inflows (Lestelle 2007).

Coho usually spawn on pool tailouts and along the margins of riffles in main channel habitats, often close to or under cover. They generally spawn in small gravels (Burner 1951). They will also use smaller substrates, even containing high amounts of sand, if there is upwelling associated with spring inflows (Lestelle 2007).

Fry emerge from their incubation sites usually in early to late spring, depending on temperature and flow regimes. The emergent fry move quickly to slow velocity, quiescent waters, usually along the stream's margins or into backwaters where velocities are minimal, a consistent behavior across the species range (Sandercock 1991; Nickelson et al. 1992; Hampton 1988; Nielsen 1994; CDFG 2002). This affinity for slow velocity areas remains characteristic of juvenile coho throughout their freshwater life, unlike most other salmonid species.

Juvenile coho typically spend one year—though this can vary depending on thermal regimes—rearing in fresh water, during which time they may remain close to their natal sites or they may move long distances to find suitable summer and/or overwintering habitat. Their movements can disperse them to streams of all sizes—from tiny rivulets to large rivers and all sorts of connected water bodies, including lakes, ponds, groundwater channels, flooded wetlands, and estuarine areas (Lestelle 2007).

Movements to find suitable summer habitat can be triggered by excessively warm water temperatures or severely diminished flows. This pattern has been documented in the Shasta River (Chesney and Yokel 2003; Chesney et al. 2009) as well as in the mainstem Klamath River (Hillemeier et al. 2009). In the Shasta River, juvenile coho move out of the river during summer to find refuge in small springs along the river or along Parks Creek. On the Klamath River, juvenile coho will start leaving the mainstem river when temperatures exceed about 19ºC to take refuge in small cool water tributaries. The extent of the evacuation out of the mainstem appears to be very substantial as temperatures approach 22ºC (Hillemeier et al. 2009).

A similar type of redistribution, only covering much longer distances than seen in summer, can occur in the fall and early winter as juvenile coho seek suitable overwintering habitat (Lestelle 2007; Soto et al. 2008; Hillemeier et al. 2009). Coho strongly prefer very slow velocity habitats during winter—the slower the better. Harsh winter conditions for survival exist in many streams of the Pacific Northwest and Northern California, due either to frequent high flows in western regions or to prolonged cold temperatures in eastern regions (Brown 2002). Limited winter habitat is believed to be a major constraint on coho populations in many Pacific Northwest watersheds (Moyle 2002; Lestelle 2007).

In the Klamath Basin, recent studies document that juvenile coho can redistribute from summer rearing sites by at least 150 miles to find suitable winter rearing sites (Hillemeier et al. 2009; Karuk and Yurok tribes, *unpublished*). These long distance movements are in a downstream direction. Movement over such distances in seeking suitable habitats can occur during night in the midst of major freshet conditions when the river is running at high flow. This fact gives pause to this author to wonder what difficulties must exist for these small fish to find suitable habitat under such conditions.

The need for coho to redistribute during either summer or winter to find suitable habitats raises the question of the cost involved to do so—where cost is measured in mortalities that might occur to some fish undertaking such journeys. There can be no doubt that the cost to the populations is not trivial when these types of redistributions are extensive. But for such life history tactics to be beneficial to the population as a whole the rewards need to exceed the costs. This implies that the alternative to such journeys—staying at the site where they reside—may exact a greater toll.

Movements of the types described above indicate that the habitats from which the fish are leaving provide less than optimal conditions for survival—likely much less (Van Horne 1983; Winker et al. 1995). In the cases of the summer and winter redistributions described above, we know that this is true. Some fish that continue to reside in areas of high temperature will succumb. Habitats subject to high velocity or fluctuating flows in winter produce poor overwinter survival for coho.

It is important to recognize here how certain characteristics of habitats can affect the survival of animals that require some type of searching to find suitable refuge sites. Survival will be related to the probability of finding refuge sites. If the probability is low, then the likelihood for being stressed or dying increases, and vice versa. The probability of finding suitable sites is related to the number of such sites that exist and their distribution along the pathways being used by the animals in relocating. Where more suitable sites exist, their distribution is more widespread, and there exists good connectivity between sites, then the likelihood for animals to succeed in finding them improves. (The reader should note that such conditions are an aspect of habitat quality as pertains to its effect on population performance.)

In the historic Shasta River, habitats were probably optimal for summer rearing in much of the river and favorable for winter rearing. The thermal regime and steady flows during summer, combined with high food abundance, would have resulted in high survival and good growth. There would not have been much need for juveniles to relocate to escape high temperatures, though this may have occurred in the lower portions of the river. With the onset of winter and higher, fluctuating flows generated at higher elevations, juvenile coho would have easily found suitable conditions for overwintering in the marshes near Carrick Creek, in the low gradient areas of lower Parks Creek, and in the highly sinuous, low gradient mainstem Shasta River channel coursing through the valley. Sufficient structure for probably existed in all of these areas to help promote high survival. Some juveniles probably left the Shasta River to seek overwintering elsewhere during major storm events.

Juvenile coho salmon that attain a certain size by late winter or spring undergo smoltification—the physiological transformation necessary for surviving at sea. The great majority of coho smolts in California, Oregon, and Washington attain the necessary size as yearlings, triggering them to move seaward in spring of their second year of life. Their survival during their seaward migration can be affected by many factors, including distance to the ocean, water temperature, predator abundance, pathogens, physical barriers within the stream, and flow characteristics (Quinn 2005; Lestelle 2007). The pattern and level of flow can be particularly important for facilitating successful outmigration from off-channel habitats and stream sections containing beaver dams (Lestelle 2009).

A final note is needed to recognize that it is likely that the historic Shasta River produced some subyearling coho smolts in addition to typical yearling smolts. There is growing evidence that the river continues to do so owing to the very rapid growth that occurs for young-of-year fish in spring (Bill Chesney, *personal communications*; Yurok Tribe, *unpublished data*). I am unaware of any other river where such rapid growth occurs that would result in subyearling coho smolts. This life history type is one that can be produced artificially using hatchery technology. It requires accelerating egg incubation time and initial fry growth to achieve large size much earlier than is normally seen in nature (Feldman 1974; Feldman and Lestelle 1976; Brannon et al. 1982). If juvenile coho achieve a size of approximately 10 cm by sometime in late spring or early summer, then smoltification can develop and they will successfully migrate to the ocean. This results in the fish returning as two-year olds to spawn, cutting a full year off their life cycle.[25]

On the basis of some evidence that such a life history is still occurring for some Shasta River fish, I think it is likely that this life history type may have been relatively common in the historic river (though not as common as yearling smolts). If this is the case, then it is likely that there may have been some genetic component to facilitate such a life history tactic in the historic population (more so than in other populations). A coho population that expresses a “hurry-up” life history type in addition to the traditional three-year old life history type would likely be much more productive and more stable than populations that cannot express both types.

4.2.2. Spatial Use by Life Stage of the Shasta River

This section presents my conclusions about the spatial use of the Shasta River for each life stage by species in the historic and modern day river. My conclusions are based on the characteristics of the river, as previously described, and on knowledge of the life histories of the species. How the populations used the river historically and how they do so today provide a basis for drawing conclusions about limiting factors and the effects of Dwinnell Dam.

My conclusions are presented in graphic form in Figures 24 and 25 for the historic and current time periods respectively. I have only addressed here the distributions of use for the mainstem

[25] / These fish are not jacks. Jacks spend only several months in the ocean. Subyearling smolts that return as two-year olds spend close to 18 months in the ocean.

river. Similar graphics could be developed for each of the tributaries, though I believe the focus here on the mainstem is sufficient for this level of diagnosis.

The graphics in Figures 24-25 display relative use of the river between the river mouth and the upper most reach in the river used by salmon in the historic condition. Usage is shown color coded as being in one of four categories: negligible, low, medium, and high. Life stages shown are spawning, spring and summer rearing (for young-of-the-year), and overwintering.

For current conditions, my conclusions shown in Figure 25 take into account the relative utilization in a way that considers the relative numbers of fish present. Hence, the low population size of coho today has a strong effect on how I assessed spatial use.

It is important to recognize that my conclusions presented here represent hypotheses about how I think the historic populations used the river, as well as for existing populations.

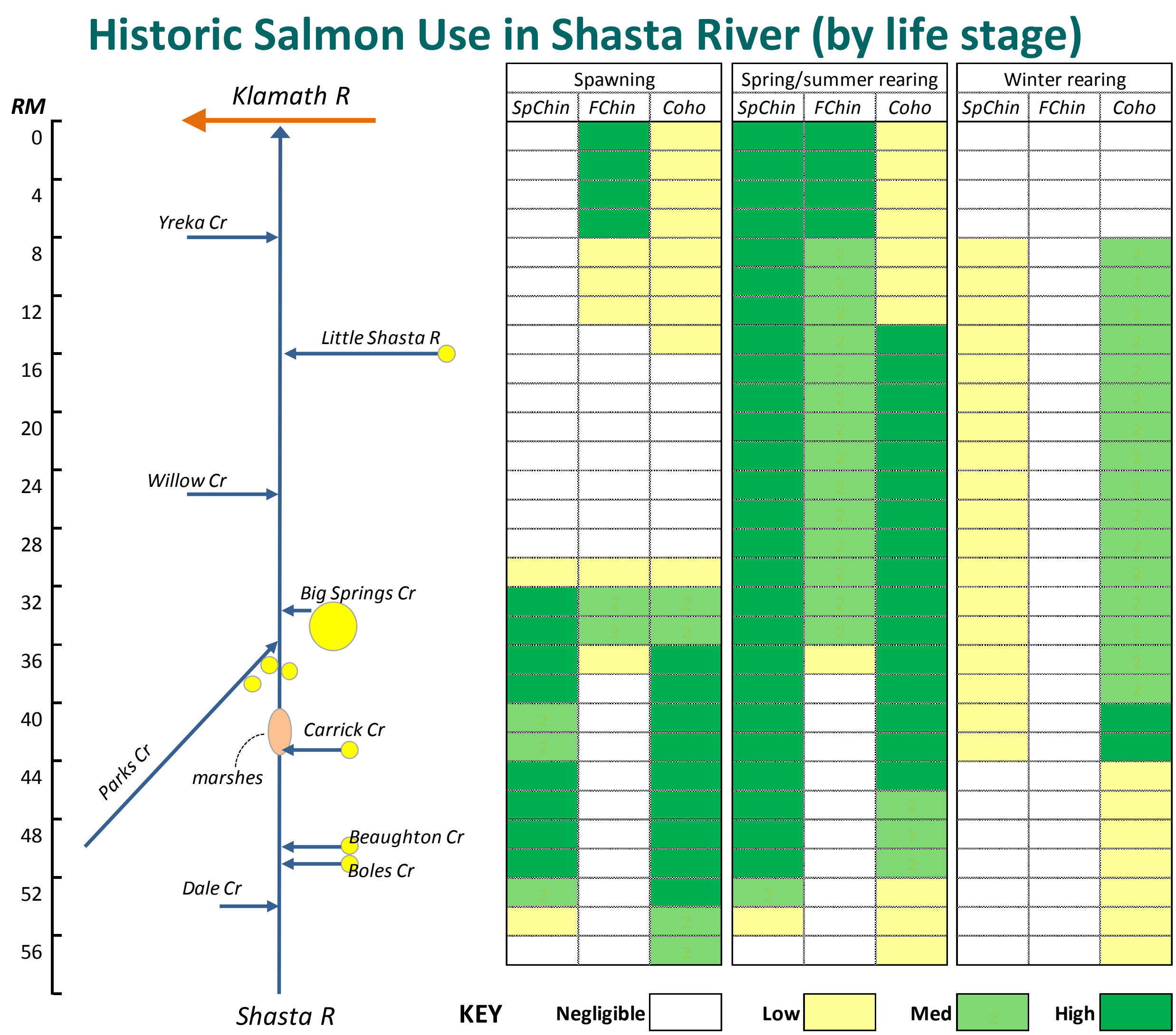


Figure 24. Relative usage of the historic Shasta River in different life stages for spring Chinook, fall Chinook, and coho.

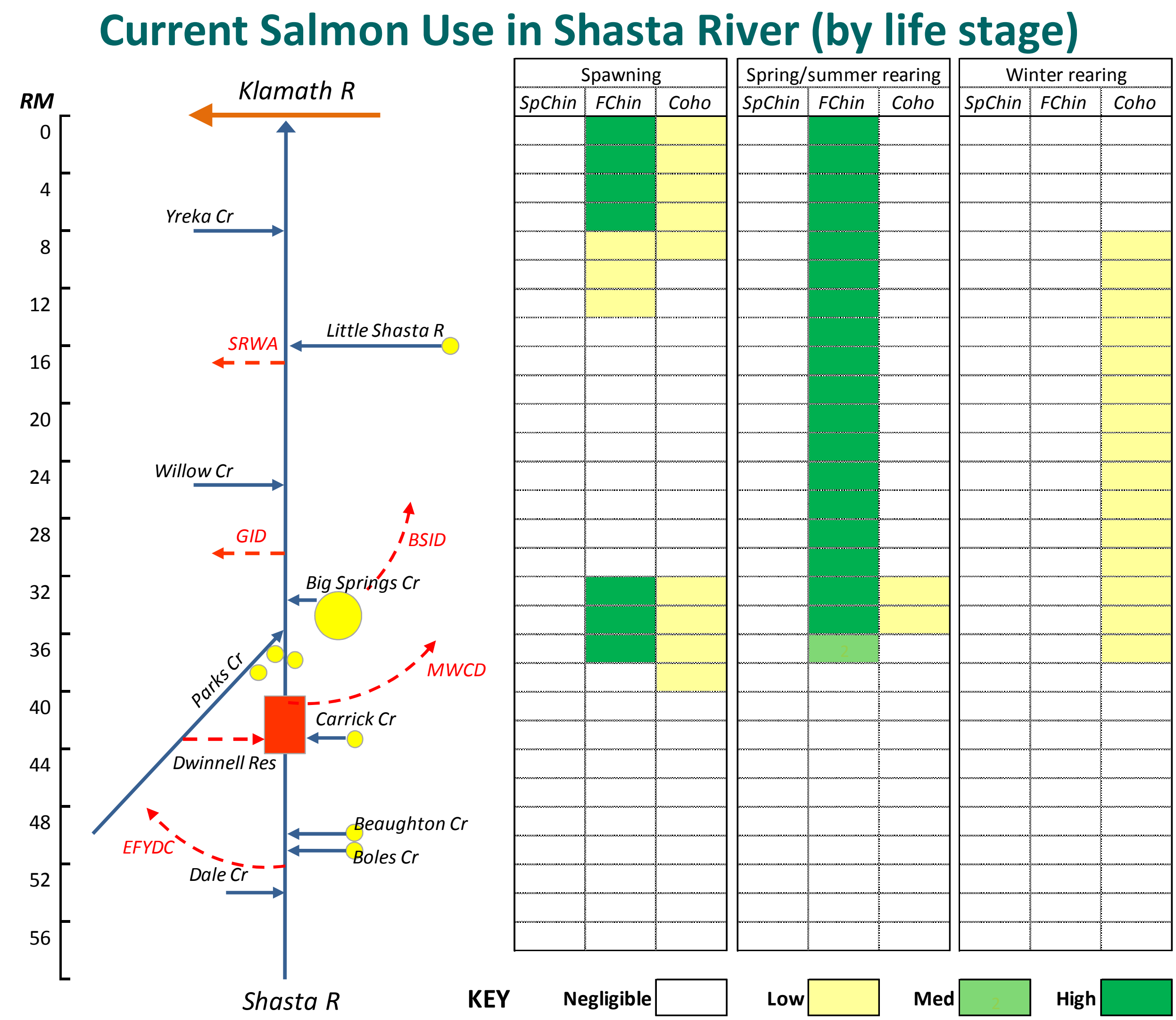


Figure 25. Relative usage of the current Shasta River in different life stages for spring Chinook, fall Chinook, and coho.

4.3. Limiting Factors

This section presents my conclusions about habitat factors that affect population performance for the three populations of interest to this document. My conclusions are based on the characteristics of the river, as previously described, knowledge of the life histories of the species, and my understanding about how the various factors can affect survival.

I present my conclusions in a qualitative manner, as I described the approach in the introduction to this report. The habitat factors considered are temperature, flow characteristics, dissolved oxygen, irrigation screens, barriers to migration, habitat structure, habitat quantity, gravel quality, and presence of exotic fishes. My conclusions are shown for the entirety of the life of the salmon that might be spent in the various locations of the river.

My conclusions are presented in graphic form for spring Chinook (Figure 26), fall Chinook (Figure 27), and coho (Figure 28). Similar to the previous section on spatial use by salmon, I have only addressed limiting factors along the mainstem river. Comparable graphics could be developed for each of the tributaries, though I believe the focus here on the mainstem is sufficient for this level of diagnosis.

The severity of each factor as I have concluded it probably operates is shown color coded as being in one of four categories: negligible, low, medium, and high. Note that I present my conclusions as if the historic distribution of the population is present, i.e., how the factor would operate if fish of that population were present.

It is important to recognize that my conclusions represent hypotheses about the relative severity of each factor on the basis of my understanding about the condition of the factor and how the factor potentially affects fish performance.

Water temperature is shown to be the most limiting factor overall on the performance of spring Chinook and coho. It must be recognized, as noted earlier in the report, that temperature effects are closely related to changes in the flow regime, which are the result of various water management activities, including operations at Dwinnell Dam.

It should be noted that Dwinnell Dam, acting as a barrier to fish migration, is shown as having a severe effect just at the location of the dam. The dam blocks an estimated 36 miles of stream habitat for coho—so the reader should keep in mind that the color coding in Figures 26-28 are site specific. A severe rating at one location for one factor can trump the effect of a severe rating for another factor over a long distance of stream.

An important conclusion is that many factors in the subbasin operate in combination to affect how populations can perform in the Shasta River in its current state. Recovery actions need to be planned considering all of these factors and how they operate spatially and temporally over the course of a year.

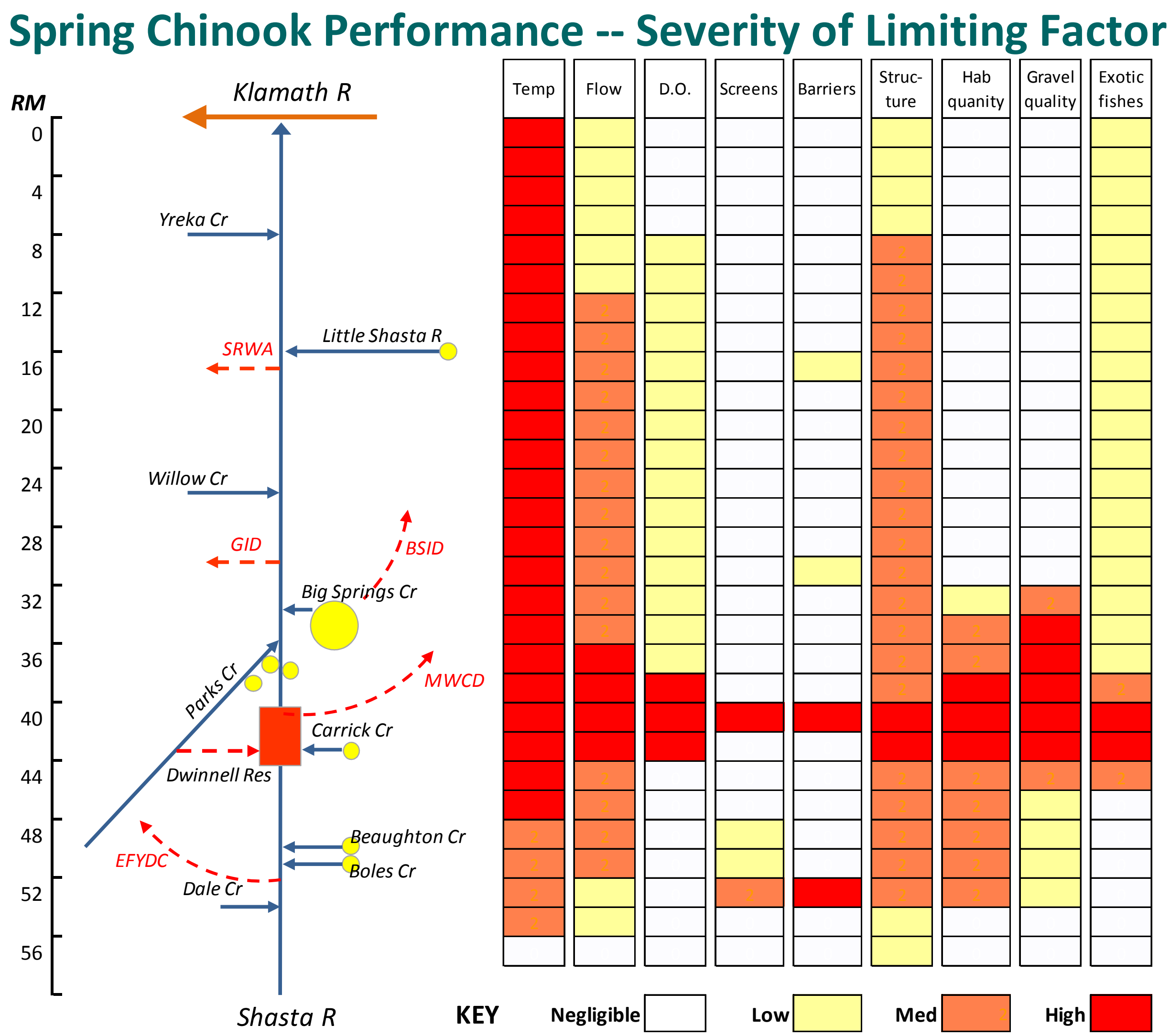


Figure 26. Relative severity of different habitat factors on the performance of spring Chinook if they were present in the Shasta River, assuming historic distribution. The severity ratings are qualitative.

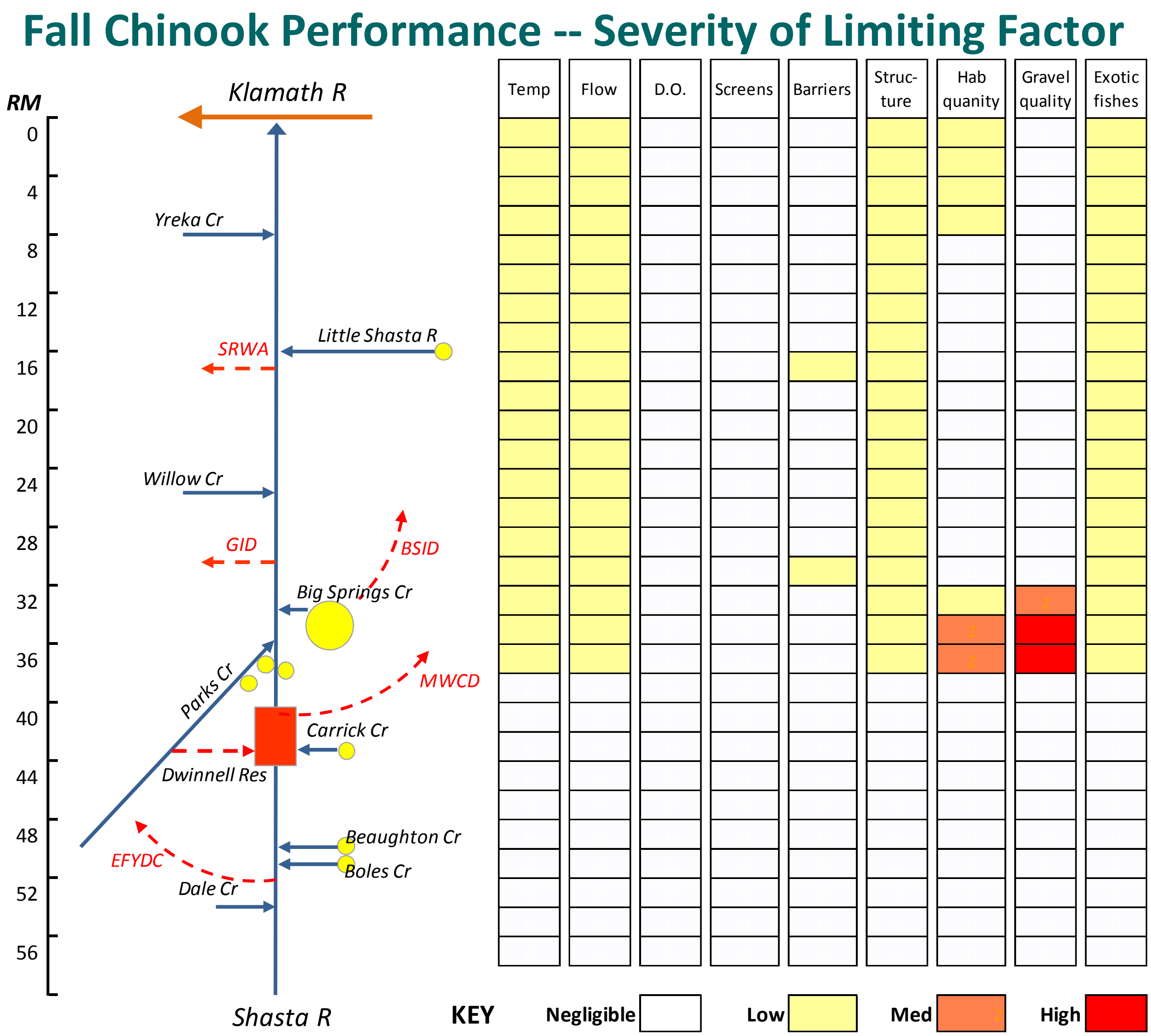


Figure 27. Relative severity of different habitat factors on the performance of fall Chinook in the Shasta River, assuming historic distribution. The severity ratings are qualitative.

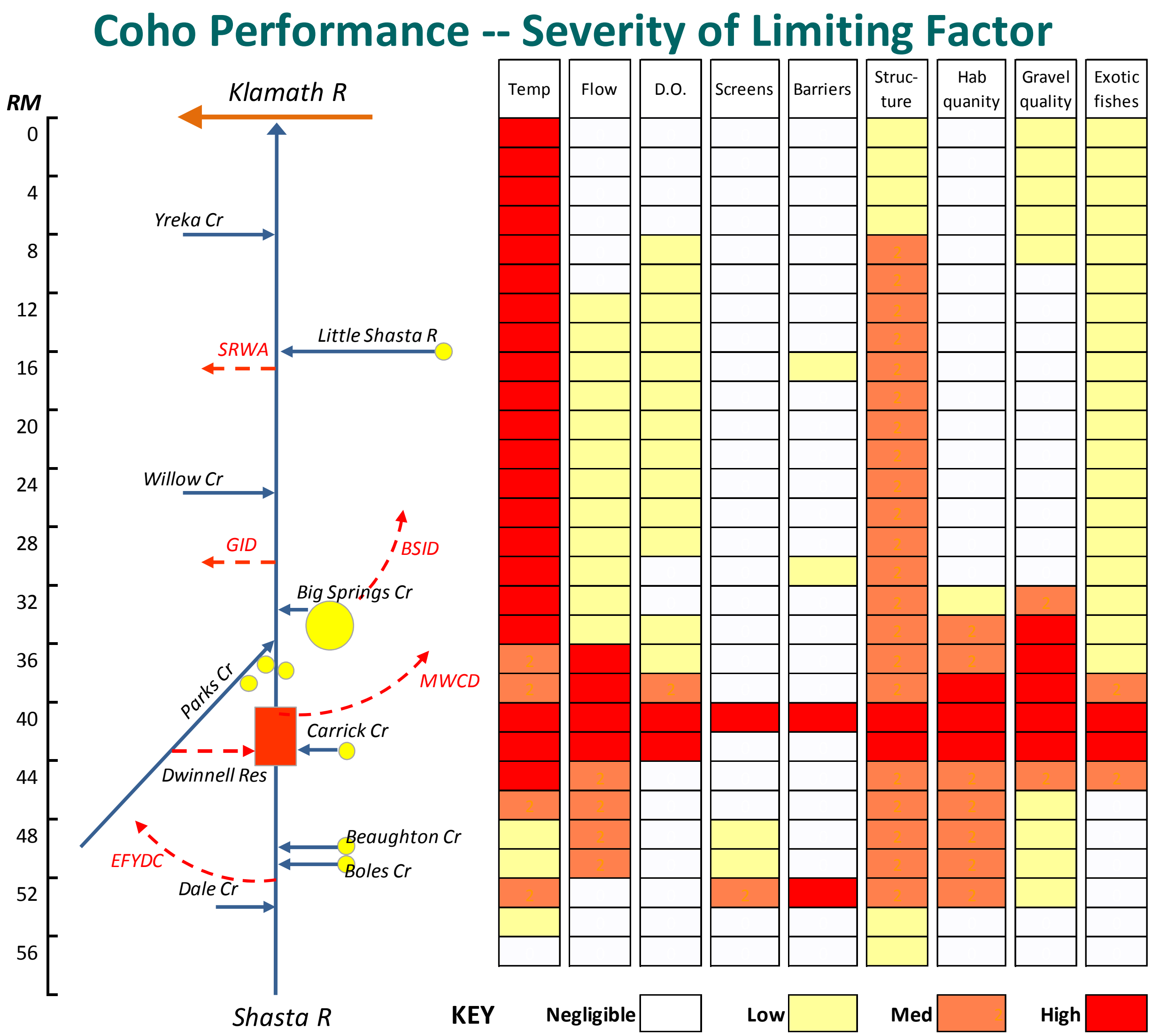
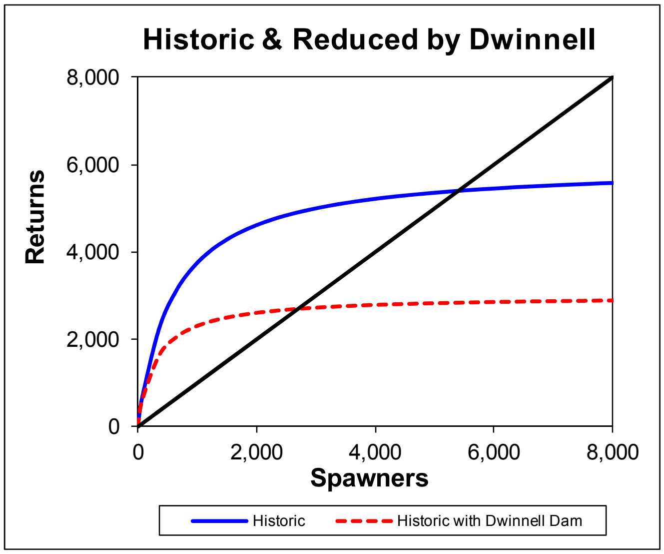


Figure 28. Relative severity of different habitat factors on the performance of coho in the Shasta River, assuming historic distribution. The severity ratings are qualitative.

I illustrate below how I believe these limiting factors generally operate to affect the performance of the Shasta River coho population. A basic understanding of the concepts presented here is helpful in seeing how I arrive at my diagnostic conclusions and the priorities that I place on recovery actions. I build on the concepts introduced in the Section 3.3 of the report (Viable Salmonid Populations) where I showed how habitat quality and quantity interact to produce the underlying relationship between spawner abundance and resulting production. The two parameters of the relationship are defined by productivity (affected mainly by habitat quality) and capacity (affected by habitat quantity)—the interaction of the two parameters results in the average abundance for a population as discussed in Section 3.3.

Figure 29 (top) illustrates the effect of reducing the availability of the historic habitat in the subbasin by half and leaving productivity (or habitat quality) unchanged. This is a simple scenario that would represent the outcome of building Dwinnell Dam and blocking all upstream migration at that point. This scenario, of course, is unrealistic because habitat quality had already been altered in the subbasin and the operation of the dam itself also affected habitat quality. But the example is helpful to show the effect of the barrier to migration alone. In this case, the average abundance that would result is reduced by approximately half of the average historic abundance (the point where the straight replacement line crosses the production curve).

Parameter	Historic	Dwinnell
Capacity C	6,000	3,000
Productivity P	10.0	10.0



Parameter	Historic	Current
Capacity C	6,000	3,000
Productivity P	10.0	0.7

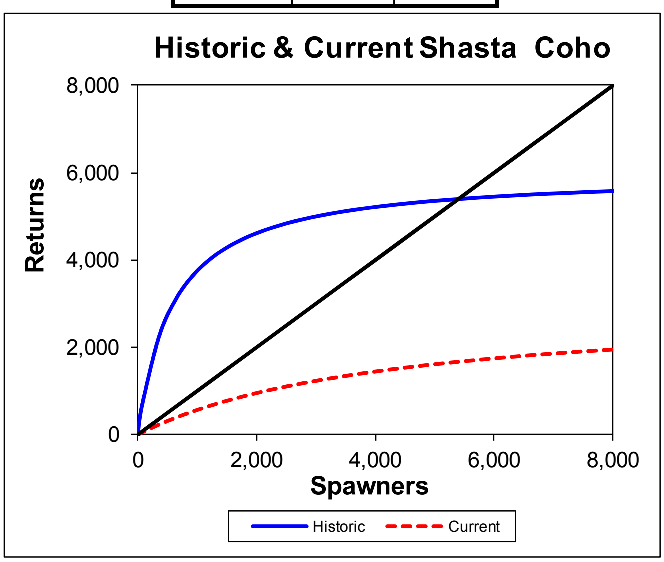


Figure 29. (Top) Conceptual relationship between number of spawners and resulting adult returns for the historic Shasta River coho population and for the same with Dwinnell Dam in place blocking migration. (Bottom) Reasonable depiction of the current performance of Shasta River coho is added. See text.

Figure 29 (bottom) adds in the effects of altering habitat quality in the subbasin by reducing the productivity parameter to a value of 0.7. This value was obtained by fitting the production curve to the empirical data that exists for the population beginning with brood year 2001. The only data available at the time of writing this report were for brood years 2001-2007. Brood year 2007 produced the return in 2010. It should be noted that use of the adult return data (back to Shasta River) are a good representation of total adult production because the level of fisheries is currently very small on Klamath wild coho. Figure 30 rescales the current production curve seen in Figure 29 so that the reader can see the data plotted. Of the seven brood years with adult return data, the population only replaced itself in one year (meaning the data point is higher than the replacement line).

Parameter	Historic	Current
Capacity C	6,000	3,000
Productivity P	10.0	0.7

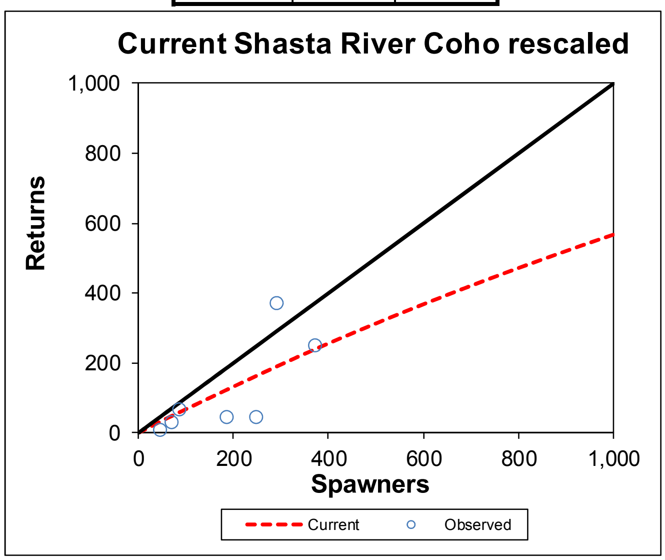


Figure 30. The current river production curve for Shasta River coho is rescaled in this figure from Figure 29 so that the empirical data can be seen when plotted.

A productivity value of less than 1.0 dictates that the production curve does not rise to ever exceed the replacement line for the current condition scenario. This condition means that the Shasta River coho population is at very high risk of going extinct soon. Moreover, the reason that this condition is occurring is that habitat quality is so severely degraded in the subbasin, as evidenced by the low productivity value.

It is noteworthy that the recent restoration activities along Big Springs Creek, together with some other beneficial activities such as fencing on the Emerson properties (upstream of Big Springs Creek), have provided some improvement in habitat quality in parts of the subbasin. Benefits of the improvements in Big Springs Creek would not yet be evident in any of the adult returns considered in the analysis shown in Figure 30. It is my judgment, however, that benefits will not result in a significant improvement to the productivity parameter seen in Figure 30. This matter is covered further in the section on setting restoration priorities.

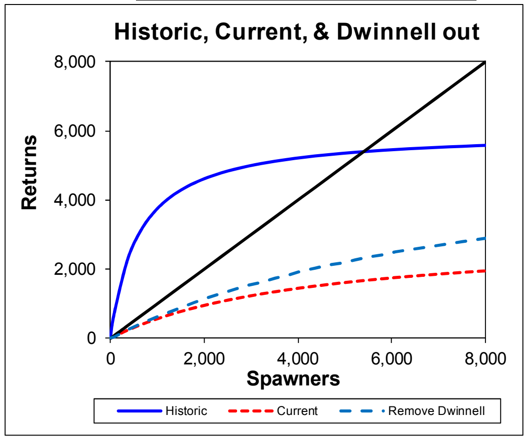
Figure 31 illustrates three hypothetical strategic approaches for attempting to revive the population and achieve recovery. The three examples, purposely kept simple here for the sake of illustration, provide insights for developing a comprehensive recovery strategy. Figure 31 (top) shows the effect of removing the barrier to migration at Dwinnell Dam (but note that in reality other barriers besides Dwinnell Dam also now exist in the subbasin). In concept, this approach would restore the full availability of habitat to the subbasin. No improvements to productivity (habitat quality) are assumed in this hypothetical case as it does not assume changes to the diversions made possible by Dwinnell Dam or due to restoration activities that may be associated with dam removal. Obviously, in reality the effects of dam removal on habitat quality are complex, and a full assessment of dam removal would need to consider these factors. In our hypothetical scenario, no real benefits to the population are provided under such a simple scenario because productivity is driving the population—extinction would still be expected.

Figure 31 (middle) shows the result of making a major improvement in habitat quality within the geographic range currently available to the population. In this case, no change is made to the amount of available habitat. Such an action, to be truly effective, would need to include a reduction in flow diversion as it now exists in the operations of Dwinnell Dam, i.e., there would need to be some return to more normative flow characteristics in both Parks Creek and those passed downstream to the Shasta River at the dam. Under this scenario, the average population size jumps to about 1,900 fish. The level of improvement in habitat quality (measured through productivity) in this case is significant, yet realistic for what should be able to be achieved. Such a scenario would need to include significant restoration to the river reaches upstream of Big Springs Creek and in Parks Creek. Actions that targeted restoration to normative levels of temperature, gravel quality, the number and distribution of refuge sites, habitat structure, flows, and connectivity would need to be implemented. If actions could be implemented to achieve an even higher productivity—which I believe is also possible—still greater response in population performance could be expected.

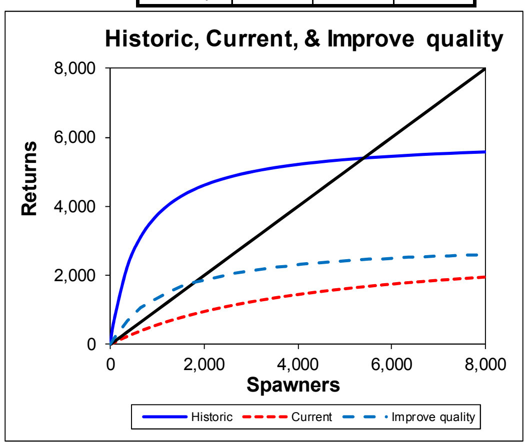
Figure 31 (bottom) illustrates the potential results of full restoration of habitat availability in conjunction with significant improvements in habitat quality (productivity is kept equal to the value used in the middle graph). The population abundance would be approximately doubled from (to about 4,000) from the level seen in the previous example.

These simple examples illustrate that the first priority for moving toward population recovery of coho in the subbasin should be on restoring habitat quality. As quality is improved, this would serve to also expand the range of habitats that could be used within the existing stream reaches now accessible to coho downstream of Dwinnell Dam. Once that is accomplished, expansion of the distribution of coho into the areas upstream of Dwinnell Dam could then proceed more effectively.

Parameter	Historic	Current	Scenario
Capacity C	6,000	3,000	6,000
Productivity P	10.0	0.7	0.7



Parameter	Historic	Current	Scenario
Capacity C	6,000	3,000	3,000
Productivity P	10.0	0.7	2.5



Parameter	Historic	Current	Scenario
Capacity C	6,000	3,000	6,000
Productivity P	10.0	0.7	2.5

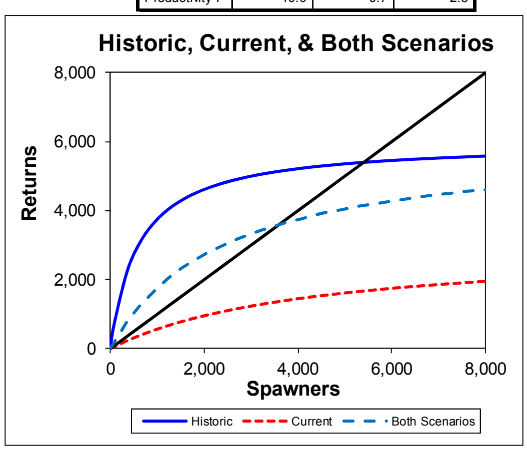


Figure 31. Conceptual results for three hypothetical strategic approaches for attempting to recover Shasta River coho: Top – removal of Dwinnell Dam with no other changes; Middle – major improvements in habitat quality and keeping Dwinnell Dam in place; Bottom – Removal of Dwinnell Dam along with major improvements in habitat quality.

4.4. Diagnostic Summary

Many factors, acting in concert for longer than a century, are responsible for the steep losses in the salmon resources of the Shasta subbasin. Among these, the construction and operations of Dwinnell Dam have very likely had the most significant effects overall. The effects associated with Dwinnell Dam were direct and immediate, as well as indirect affecting watershed processes that extended the range of effects to stream reaches many miles downstream. The influences of altered watershed processes continue to the present time.

The dam acted to essentially sever the upper part of the main river from the lower and middle parts of the subbasin, significantly altering the natural flow and sediment regimes and blocking all salmon migrations at that point. These effects in themselves would have been disproportionately much greater than others brought about by previous events associated with land and water uses. The severity of disruption to physical, ecological, and biological processes no doubt far exceeded disruptions associated with other prior land and water uses.

It is my view that the building and operations of the dam may have also had a more subtle indirect effect. It is reasonable to think that it contributed to how land owners and water users may have perceived the watershed and its salmon resources. Since the upper watershed was so altered due to the dam and the many changes in brought, more barriers and more water diversions and more disruptions to the streams might have been perceived as having little consequence.

The building and operations of Dwinnell Dam have affected the salmon resources of the Shasta River in the following ways:

- The dam blocked access by spring Chinook to the upper reaches of the watershed—in both the mainstem river and several of its spring-fed tributaries; these areas were likely the core spawning areas of the historic spring Chinook population. This loss of access was the death knell for this population.

- The dam blocked access to approximately 36 miles of stream habitat for coho, most of which would have served as important spawning areas for this species, besides providing both summer and winter rearing habitats.[26] This loss would have resulted in an abrupt and significant drop in coho production following dam construction.

- The reservoir formed by the dam has created a variety of degraded habitat conditions within this body of water, largely related to water quality issues but also associated with seasonal changes in water level. These water quality issues—including elevated water temperatures—influence conditions downstream of the dam due to water releases that occur in summer to satisfy water rights there.

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[26] / I estimate that 36 miles of habitat were likely blocked based on an inspection of topographic maps and stream gradients.

- Water diversions associated with the operations of Dwinnell Dam have greatly changed the characteristics of the flow and sediment regimes in Parks Creek and the Shasta River. These altered regimes have adversely affected salmon habitats in both of these streams in the following ways:
  - Reductions in peak flows in Parks Creek downstream of the water diversion and in the Shasta River between Dwinnell Dam and approximately Big Springs Creek have narrowed and simplified the stream channels, reduced the diversity and quality of instream habitats, and increased the amounts of intra-gravel fine sediments (reducing the quality of the substrate for egg incubation). These changes have adversely affected the quality, quantity, and connectivity of habitats used by coho and fall Chinook.

  - Reduction in the summer flow downstream of Dwinnell Dam have exacerbated high water temperature conditions between the dam and the river mouth due to loss in water mass being discharged by the river (see text associated with Figure 20). These changes have reduced the quality of the existing habitat to support juvenile salmon rearing in the river during the affected months. Consequently, sites of thermal refuge for juvenile coho have become increasingly smaller and more isolated, making it more difficult for juveniles to find the sites and use them successfully during periods of high water temperature.

  - Reductions in flow during all seasons associated with the operations of Dwinnell Dam have reduced the amount of available habitat for all life stages of salmon in Parks Creek and in the Shasta River between the dam and Big Springs Creek.

It is my view that Dwinnell Dam is the single most important impediment to being able to make a successful reintroduction of spring Chinook in the river system. Without access to the upper watershed, the range of habitats that could be available to this species—even with significant habitat restoration in lower Parks Creek and Big Springs Creek—would likely be too small and limited to support this race. It must also be recognized that even with dam removal other habitat issues—including other barriers and diversions—would need to be addressed upstream of the current reservoir to restore spring Chinook.

The effects of the changes in the watershed associated with the Dwinnell Dam and its operations on coho have been pronounced over the past 80 years. While some effects—major ones—were immediate due to blockage of the upper system to coho access, others related to changes in habitats downstream of Dwinnell Dam and the Parks Creek diversion have caused a long-term deterioration in habitats in these areas. These effects have been most significant on the quality of habitats that support coho spawning and egg incubation success and subsequent juvenile rearing and seasonal redistributions. The result of these changes has been to contract—or squeeze—the distribution where coho can survive to a very limited geographic range of habitats. Other land and water uses in these geographic areas, as well as in other areas of the subbasin, have acted in conjunction with the effects associated with Dwinnell Dam. All of these factors operating in concert have brought the coho population to the brink of extinction in the subbasin.

The effects of the factors so detrimental to spring Chinook and coho have been much less on fall Chinook, though the factors likely have still had an important role in reducing performance.

5.0 Solutions – Identifying Priorities for Salmon Recovery

In salmon recovery efforts, it is usually more important to rescue and conserve the salmon life histories that currently exist before attempting to recover the ghosts of lost life histories. This principle provides guidance in setting priorities for salmon recovery.

The first priority, therefore, should be to restore normative functions of habitats that are currently within the geographic range of distributions used by coho and fall Chinook in the subbasin. In particular, this priority would be focused on restoring habitats used by coho between Big Springs Creek and Dwinnell Dam and within Parks Creek. Actions would be aimed at reducing the effects of Dwinnell Dam and its operations on habitats in such a way as to expand the range of suitable habitats, including their connectivity during all seasons. This priority might include some aspects of the bypass alternative described by Tom Cannon so that fish could more fully utilize Parks Creek downstream of the existing diversion of water from Parks Creek to the upper Shasta River.

The second priority would be to expand accessible habitat to include more of the historic range of distribution, including those areas upstream of Dwinnell Dam. This priority could include the removal of Dwinnell Dam or implementation of the bypass alternative described by Tom Cannon so that fish could regain access to the upper watershed.

With successful dam removal—or the bypass alternative described by Tom Cannon—along with other restoration activities, a reintroduction of spring Chinook could be planned and implemented.

5.1. Conserve and Improve Existing Core Habitats and Associated Life Histories

The first priority should be given to restoring normative habitat functions within the areas currently accessible to coho and fall Chinook in the subbasin. Actions that could be implemented quickly and effectively could rescue the remnant coho population from extinction. To do this would require making a significant improvement in the quality and connectivity of habitats within the geographic range currently used by the population.

The elements of an action plan to achieve these objectives should include the following:

- Continued efforts to restore Big Springs Creek in the manner that actions have already been taken (this level of effort would continue to accommodate flow management from the spring sources as laid out in existing restoration plans);
- Restoration of spring and stream habitats, including their riparian corridors, within the Emerson properties; this would include channel and flow restoration to affected reaches of the mainstem Shasta River and Parks Creek;
- Restoration of a more normative flow regime released out of Lake Shastina to the Shasta River—care would need to be taken to do this in a way not to disrupt the positive effects

of cool water inflows from springs downstream of the dam; among many benefits, this action would help facilitate successful smolt outmigration during the spring period;

- Restoration of a more normative flow regime in Parks Creek by reducing the amount of flow diverted from this stream to the upper Shasta River during winter and spring—this action is believed to be particularly important for facilitating successful smolt outmigration during the spring period; care would need to be exercised in developing an appropriate flow schedule to be restored in Parks Creek;
- Development of an intervention plan using hatchery technology to preserve the existing coho gene pool in the Shasta River, which would include supplementation actions to reduce demographic effects.

The set of actions to accomplish this priority could include aspects of the bypass alternative discussed by Tom Cannon in his report. In concept, it would place significant attention on rebuilding Parks Creek to once again be a core habitat for anadromous fish over much of its stream length.

5.2. Expand the Range of Accessible Habitats to Historic Distributions

The second priority would be to expand accessible habitat to include more of the historic range. This priority recognizes that the range of habitat currently used by coho in the Shasta River system is much contracted from what it was historically. There has been a significant loss in spatial structure and habitat diversity that is currently accessible.

I do not see this priority as needing to be addressed only after priority one has been achieved. I believe it is likely some aspects of this priority will need to be met to achieve recovery of coho in the subbasin. In that sense, there is some degree of overlap between the priorities.

As noted above, I think it is likely that successful reintroduction of spring Chinook will require restoration of a large amount of the upper parts of the subbasin, both in terms of access and habitat conditions. Also, while I have not listed it below, it may be necessary to fully restore Big Springs Creek, i.e., full flow restoration, if a spring Chinook reintroduction effort is to be successful.

An action plan to achieve the objective of this priority would include some elements of the following:

- Removal of Dwinnell Dam or development of a suitable bypass alternative through the Parks Creek drainage as described by Tom Cannon (Cannon 2011);
- Restoration of habitat conditions to normative characteristics in the upper parts of Parks Creek and the Shasta River;
- Restoration of access and habitat conditions to other tributaries or parts of tributaries previously used by coho.

6.0 Concluding Remarks

The Shasta River historically functioned as one of the most important components of the Klamath Basin's capacity to produce salmon. The unique characteristics of the Shasta River made it extremely productive for salmon. It must have also contributed considerable genetic and life history diversity beyond what the other parts of the Klamath system produced. Whether viable salmon populations can continue to be supported in the Klamath system for future generations may depend on recovering coho and spring Chinook in the Shasta River.

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