MONITORING THE EFFICACY OF JUVENILE SALMON (*ONCHORHYNCHUS SPP.)* OFF-CHANNEL HABITAT RESTORATION PROJECTS IN SOUTH CENTRAL, ALASKA

by

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THESIS

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Abstract

Four off-channel salmon habitat restorations located on Resurrection Creek, Quartz Creek, Little Campbell Creek, and the Eklutna River in southcentral Alaska were studied from May-September 2010 to determine if and how off-channel and main-stem habitats are utilized by coho salmon (*Oncorhynchus kisutch*) seasonally. Relative abundance, water quality, and physical habitat characteristics were measured at each of the four restorations. At the Eklutna River study site, a coho salmon population structure analysis was performed as well.

Coho salmon were only caught during the July-September samplings at Resurrection Creek and no coho salmon were caught in the Quartz Creek and Little Campbell Creek off-channel habitats, which had problems with connectivity, water quality, and physical habitat. Coho salmon were caught in the Eklutna River ponds throughout the study. The lower Eklutna River pond was the most productive habitat evaluated, and it supported a large summer coho salmon population of 3,490 coho salmon larger than 60 mm fork length, with coho salmon densities of 57/ 100 m². Coho salmon distribution within the Eklutna ponds was influenced by water temperature, with the highest catches in traps with temperatures between 11 and 13.5ºC. Fish reared in the Eklutna ponds tended to be older, (predominately ages 1 and 2) than fish reared in the main-stem (predominately age 0). Artificial off-channel habitats, such as the Eklutna River ponds, have the potential to increase juvenile coho salmon production, especially on heavily modified stream systems that are lacking natural off-channel floodplain habitats.

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Chapter 1: Introduction

Numerous streams throughout the Pacific Northwest have been altered and degraded by human activities such as urban development, mining, logging, and road construction (Hochhalter 2006). Increased floodplain development and the alteration and degradation of streams have led to a loss of important salmon (*Oncorhynchus* spp.) spawning and rearing habitats, and they have contributed to the decline of salmon populations in the Pacific Northwest (Roni et al. 2002). In an effort to mitigate this habitat loss, stream restoration projects have been completed to increase adult spawning and juvenile rearing habitat for salmonids in heavily impacted stream systems (Rosenfeld et al. 2008). Many of these projects are designed to create new, well connected, off-channel, rearing habitats, with the end goal of increasing juvenile salmon production (Roni et al. 2002).

Coho Salmon Life History

Coho salmon (*Oncorhynchus kisutch*) have a wide distribution throughout the northern Pacific Ocean, ranging from California to the coast of Japan (Sandercock 1991). In Alaska, coho salmon are found as far north as Point Hope on the Chukchi Sea (Wahle and Pearson 1987), and they are abundant throughout southcentral and southeast Alaska (Atkinson et al. 1967). Coho salmon are anadromous, spending the first one to four years of their life cycle in fresh water (Engel 1968; Drucker 1972). Adult coho salmon spend one to two years in the ocean, feeding on invertebrates and small fish. Generally, they reach maturity after one year at sea, although over half of Alaskan coho salmon remain at sea for two years before returning to their native streams and rivers to spawn (Royce et al. 1968).

The coho salmon life cycle begins when adults return from the ocean to spawn in coastal streams. In northern latitudes, such as Alaska, coho salmon return to their native streams earlier than coho salmon in southern latitudes, with runs starting in July and continuing through November (Briggs 1953; Godfrey 1965). Earlier spawning in colder climates allows time to compensate for slower egg development (Briggs 1953; Shapovalov and Taft 1954). In Alaska, spawning occurs in small headwater streams and tributaries from October to November (Crone and Bond 1976).

Prior to laying eggs, the female coho salmon selects a nesting site in gravel substrate at the head of riffles or in areas of upwelling, and digs a depression to create a nest, or redd (Shapovalov and Taft 1954). The female releases eggs into the redd while a male simultaneously releases sperm to fertilize the eggs (McPhail and Lindsey 1970). The female then covers the nest with substrate to protect the eggs from predators (Briggs 1953). The average female carries 3,100 to 4,500 eggs (Engel 1967). Both the male and female die shortly after spawning, usually within 11-13 days (Crone and Bond 1976).

The deposited eggs incubate in the gravel for approximately 100-115 days depending on temperature (Berg 1948). After hatching, the larval fish, or alevins, remain in the gravel where they feed on their yolk sacks until April or May. Many environmental factors influence egg and alevin survival rates, with high mortality occurring due to winter flooding, sedimentation, disease, predation, and freezing within the gravel (Neave and Wickett 1953). Under average environmental conditions less than 27% survival is expected (Crone and Bond 1976), and with excellent conditions survival can be as high as 86% (Shapovalov and Taft 1954). Ten to 47 days after starting to emerge from the gravel (Koski 1966), the coho salmon alevins turn into approximately 30 mm long fry (Gribanov 1948). Typically, early emerging fry are larger than those that emerge later in the spring, and these larger fry maintain their size advantage outcompeting later emerging fish for territories and food (Mason and Chapman 1965).

Coho salmon fry utilize shallow, lower velocity areas, and prefer complex streams with undercut river banks, small tributaries, backwater areas, side-channels, large woody debris, and vegetative cover (Gribanov 1948; Lister and Genoe 1970). Coho salmon fry establish territories in these habitats where they can easily feed on macroinvertebrates and other insects, and they aggressively defend their territories from other fish (Mundie 1969). When the fry reach 38-45 mm in length, they can migrate upstream to pond, lake, and headwater rearing habitats (Godfrey 1965; Mason 1974). In the fall, when water flow increases in the main-stem channel, coho salmon migrate to spring-fed ponds (Peterson 1980), beaver ponds, side-channels, and other types of off-channel rearing habitats to overwinter (Narver 1978). They remain in these off-channel habitats until spring when they move into the main-stem channel (Tschaplinski and Hartman 1983).

Juvenile coho salmon growth is highly variable, depending on water temperature and food abundance. In lower latitudes, the majority of coho salmon fry rear in freshwater streams for one year with smaller numbers staying up to four years before migrating to the ocean (Sandercock 1991). At northern latitudes, coho salmon stay in freshwater longer to compensate for slower growth rates. In southeast and southwest Alaska, over 50% of coho salmon in the Taku River (Meehan and Siniff 1962), Hood Bay Creek (Armstrong 1970), and Karluk Lake (Drucker 1972) were two years old at outmigration. Coho salmon grow rapidly during the spring and early summer, with growth slowing during mid-to-late summer and ceasing in mid-winter (Mason 1974). Coho salmon can reach 60-70 mm by September of their first year (age 0) and 80-95 mm by the following spring (age 1; Rounsefell and Kelez 1940). Juvenile Alaskan coho salmon begin migrating to the ocean and undergoing smoltification in mid-May when water temperatures are between 5.0 and 13.3°C (Drucker 1972), with migrations peaking in June

(McHenry 1981). Coho salmon smolt will stay in near shore estuaries for several months prior to migrating further to adult feeding grounds (Miller and Sadro 2003).

Coho salmon mortalities are highest during their freshwater rearing phase with only one to two percent surviving from eggs to smolts (Neave and Wickett 1953). However, coho salmon survival from smolt to adulthood is over three times higher than survival for other salmonids, such as pink (*O. gorbuscha*) and chum (*O. keta*) salmon, because the longer freshwater rearing time allows them to grow to a large enough size (100 mm) to reduce ocean predation (Drucker 1972). In addition to high rearing mortality rates, coho salmon populations are limited by amount and quality of in-stream and off-channel rearing habitat (Nickleson et al. 1992). Since mortality is highest during the freshwater rearing phase of the coho salmon life cycle, and the amount and quality of in-stream habitat limits productivity, creating quality rearing habitats on impaired and degraded stream systems is one important step that can help improve juvenile coho salmon production.

O***ff-channel Salmon Habitats***

Juvenile salmon use various types of off-channel habitats for rearing. These can be divided into two major types, lentic (or still water) and lotic (or flowing) side-channels. Lentic habitats include beaver ponds, naturally created side-channel ponds, artificially constructed ponds, alcoves, and sloughs that are connected to the main-stem channel but do not receive significant water flow; or they can be solely groundwater fed. Lotic off-channel habitats, connected to surface water flow, can also be natural or artificially built. Many stream restoration projects combine several habitat types to artificially create complex, interconnected, off-channel fish habitats (Rosenfield et al. 2008). The focus of modern stream restoration is shifting towards restoring the stream processes that create and maintain off-channel habitats (Roni et al 2002).

When stream processes, such as channel morphology and flow regime are restored, the stream naturally creates off-channel habitats that are compatible with the natural environment and organisms living in the stream system (Roni et al. 2002).

Typically, coho salmon move into off-channel habitats in the late summer and fall months when water velocities increase and water temperatures decrease in the main-stem channel (Bramblett et al. 2002). In a British Columbia river, coho salmon overwinter in off-channel habitats that have low water velocities, such as ponds, small lakes, and backwater sloughs (Swales and Levings 1989). They remain in the off-channel until late May and early June when they migrate to the ocean (Swales and Levings 1989). Off-channel habitats provide refuges from high water and flood conditions, and they are utilized by rearing coho salmon throughout the summer in inland streams as well (Bustard 1986).

Comparisons of juvenile salmon production in natural, off-channel and main-stem habitats indicate that the former can be more productive. Coho salmon densities can be higher in beaver ponds and beaver impounded areas than in main-stem pool habitats (Leidholt-Brunner et al. 1992; Bryant 1984). In the Coldwater River beaver ponds yielded five to ten percent of total smolts for the river system, with a 10,000 m^2 pond containing a population of 4,000 juvenile coho salmon (Swales and Levings 1989). Additionally, coho salmon rearing in ponds are typically larger and have increased survival rates (Swales and Levings 1989; Rosenfield 2008).

While salmonid use of natural off-channel habitats is well documented, their use of artificially constructed off-channel habitats is not fully understood. A series of artificial, off-channel, mined and dredged ponds had high densities of rearing chinook salmon (*O. tshawythscha*; Richards et al. 1992). In southeast Alaska, gravel pit ponds were utilized by rearing and overwintering coho salmon, with one gravel pit supporting over 5,000 fish (Bryant

1988; Hochhalter 2006). While gravel pits are used by salmon species, they have been associated with water quality problems, such as low dissolved oxygen during the winter months (Bryant 1988). The creation of artificial off-channel habitats has the potential to increase salmon smolt production; however, further evaluation focusing on seasonal fish utilization and water quality in artificial habitats is necessary.

Water Quality

Rearing coho salmon are sensitive to water quality impairments, which can limit the productivity of populations (Reeves et al. 1989). Water temperature is one of the most important water quality parameters because it influences metabolism, growth, migration, behavior, and survival (Lee et al. 2003) and thus affects habitat selection and distribution of salmonids (Selong et al. 2001). Water temperature is influenced by vegetative cover, aquatic vegetation, depth, water velocity, groundwater input, the season, and weather conditions. In off-channel habitats and ponds with little vegetative cover, summer water temperatures can exceed the tolerance of juvenile salmonids (Roni et al. 2002). According to the Alaska Department of Environmental Conservation (ADEC), maximum temperature for rearing salmonids is below 15°C (ADEC 2009).

Dissolved oxygen (DO) is another important water quality parameter. High water temperatures reduce oxygen solubility in water and increase the metabolic demand for oxygen in living organisms, which leads to physiological stress (Kramer 1987). Oxygen depletion can limit respiration, growth, movement, and fish survival (Kramer 1987). Warmer water, water with an abundance of decaying vegetation and organic matter, and groundwater can all have reduced DO levels. Certain habitats, such as off-channel ponds, can have minimal DO during the winter when ice cover reduces atmospheric oxygen exchange, and can lead to fish kills (Kramer 1987). The

Alaska water quality standards require DO levels between 7-17 mg/L for rearing salmonids (ADEC 2009).

The pH and conductivity of water can indicate a pollution problem that may be harmful to fish as well. Mining, oil extraction, agriculture, waste runoff, and other forms of pollution can change water's pH, or acidity, and specific conductance, or ability to conduct electrical currents. Conductivity is influenced by inorganic solids in water, such as nitrates, phosphates, chlorides, and petroleum. When conductive compounds are present in water, conductivity will increase. If non-conductive compounds are present, such as oil, conductivity will decrease (DeBarry 2004). Alaska water quality standards for anadromous fish streams require that pH ranges from 6.5-8.5, and it may not vary more than 0.5 units above background conditions. There is no state standard for conductivity (ADEC 2009). However, the United States Environmental Protection Agency recommends that conductivity range from 150-500 μS in fresh water streams with a variety of fish species (USEPA 2010). Because water quality impairments can influence the growth and survival of coho salmon, it is important to examine water quality in artificially built habitats to ensure that they are suitable for rearing salmonids.

Problem Statement

Each year, millions of dollars are spent on salmon habitat restoration projects (Roni et al. 2002). However, many of these projects are not monitored after completion, and the effectiveness of restorations as fish habitat is not evaluated (Reeves et al. 1991). Often, when post-monitoring does occur, it focuses on physical habitat changes post-construction, such as changes in channel morphology and flow conditions rather than biological use of the habitat. Due to the expense and difficulty associated with monitoring mobile species, such as fish, biological monitoring is seldom completed. Thus, there are large gaps in our understanding of how different restored habitats are utilized by target fish species (Roni et al. 2002).

In southcentral Alaska, several restoration projects have been completed to increase and improve available off-channel habitats for rearing juvenile salmonids. Some of the completed off-channel habitat restoration projects include areas of Resurrection Creek, Quartz Creek, Little Campbell Creek, and the Eklutna River. However, like many restoration projects across the nation, salmonid utilization and water quality in these habitats has not been extensively evaluated. Thus, I selected these four sites to evaluate whether the restored habitats are utilized by salmon, and to determine which restorations provide the best habitats. The sites were selected because they were easily accessible, they represent a range of off-channel habitat restoration types, and there are very few other completed off-channel habitat restorations in the region. I focused on coho salmon because they are the predominant salmon species utilizing off-channel rearing habitats.

Study Sites

RESURRECTION CREEK

Resurrection Creek is located in Chugach National Forest on the northern Kenai Peninsula (Figure 1). The watershed drains over 260 km^2 (USDA Forest Service 2010), and the creek flows north from the Kenai Mountains to Hope, Alaska on Turnagain Arm in Cook Inlet. Resurrection Creek has been modified since the early 1900's by placer gold mining (USDA Forest Service 2010), when riparian vegetation and soils from the creek's floodplain were removed to access alluvial gravel that contained gold. As a result, the creek was straightened and confined by tailings piles over seven meters high, increasing water velocities and destroying natural off-channel pool habitats necessary for spawning and rearing fish along approximately 6.4 km of Resurrection Creek (MacFarlane 2004).

In 2005 and 2006, the United States Forest Service completed a $1.7 million project (Keith 2006) on 1.4 km of a heavily mined section of Resurrection Creek between creek km 8.3 and 9.7. The restoration was intended to restore the stream channel and floodplain to its pre-mining state by restoring natural river processes, increasing salmon spawning habitat for all five species of Pacific salmon, and improving side-channel and main-stem juvenile salmon rearing habitat (MacFarlane 2006).

The Resurrection Creek stream restoration area is classified as a low gradient floodplain channel (<2% gradient) and the substrate in the stream is dominated by boulders, cobble, and gravel (MacFarlane 2004; MacFarlane 2006). The average flow from 1967-1986 was around 274 cubic feet per second (cfs; USGS 2004). Flow peaked around 800 cfs in June and July when snowmelt was the highest and increased again during the fall with peaks in precipitation. Annual precipitation in the watershed ranged from 60 cm at the mouth to 101.6 cm in the headwaters (MacFarlane 2004). The restored habitats examined in this study consist of four off-channel ponds, a side-channel habitat constructed on the floodplain to provide rearing habitat for fish, and a main-stem habitat in which river processes were restored to natural conditions (Table 1). Coho salmon utilization of this habitat is questionable because the habitats become disconnected from the main-stem channel with changes in water flow.

QUARTZ CREEK

Quartz Creek flows 25.7 km from the Kenai Mountains in Chugach National Forest into Kenai Lake on the upper Kenai Peninsula, east of Cooper Landing, Alaska (USEPA 2010). Quartz Creek Pond is an artificially constructed pond located approximately seven kilometers up

Quartz Creek from its confluence with Kenai Lake (between km 64 and 66 of the Sterling Highway) in a Department of Transportation and Public Facilities (DOT) gravel mine (Figure 1; Ballard 2003). As a part of a stream remediation project, between 2001 and 2003 a gravel pit was deepened until it filled with groundwater and formed a large pond, and an outlet stream channel was dug, connecting the pond to Quartz Creek (Ballard 2003). The pond is approximately 34,398 m^2 (Ballard 2003). River processes were not restored on Quartz Creek during this project (Table 1). All five species of salmon are present in Quartz Creek, but the dominant species is the sockeye salmon (*O. nerka*). No tributary channels or ponds existed in this area prior to the remediation project, so fish were not naturally present in Quartz Creek Pond (King pers. comm.).

Road construction, gold mining, and gravel mining have reduced the amount of available fish habitat located on Quartz Creek. The gravel pit restoration project was intended to provide additional rearing and overwintering habitat for salmonids on the impacted Quartz Creek system. The Alaska Department of Fish and Game (ADF&G) and the DOT found that the artificial tributary and pond were used by salmonid and trout species for spawning and rearing after construction (Ballard 2003). However, a beaver dam blockage has since exposed a series of step pools, and impaired water flow and fish movements in and out of this habitat. Thus, salmonid use of this habitat is questionable (King pers. comm.).

LITTLE CAMPBELL CREEK

Little Campbell Creek (LCC) study site is located on the North Fork of LCC in Anchorage, Alaska (Figure 1). LCC is a small tributary stream to Campbell Creek, flowing 38 km from the Chugach Mountains into Turnagain Arm. The watershed encompasses 48.6 km^2, 11.3 of which are in the Municipality of Anchorage (MOA 2007). Approximately 70% of the watershed is developed, with much of the creek flowing through residential neighborhoods, with extensive impervious surfaces (MOA 2007). Street and stormwater runoff are discharged directly into the stream via pipes, impairing water quality in the creek (MOA 2007). Runoff is accelerated during rain and high flow events, increasing turbidity and suspended solids to levels lethal to fish (Schroeder 2005). During the spring and summer months, the majority of water in LCC comes from snowmelt. Flow increases in April and May when snowmelt is highest, and from August to October when precipitation increases (MOA 2007). Average annual precipitation in the watershed is 40.4 cm, and average stream flow conditions range from 1-2.5 cfs (MOA 2007). In winter, stream flow is predominately groundwater fed. Slopes in the restoration area are less than three percent, making it a low grade floodplain channel (MOA 2007).

From 1990 to present, the creek was included on Alaska's 303(d) List of Impaired Waters by the ADEC for exceeding fecal coliform limits (MOA 2007). Additionally, urban development on the floodplain and channelization have minimized the amount of off-channel habitat available for rearing salmonids and decreased the quality of available fish habitats (MOA 2007). Although the creek is impaired, it provides rearing habitat for juvenile coho and Chinook salmon, and juvenile and adult Dolly Varden (*Salvelinus malma*) and rainbow trout (*O. mykiss*; Schroeder 2005). In an effort to provide a fish refuge from high flow and turbidity events and reduce fish kills, an off-channel alcove was built by the Anchorage Waterways Council on the North Fork of Little Campbell Creek in 2007. The total project cost was $100,000, of which $65,000 in services was donated. The alcove consists of a shallow channel of water wrapped around artificial islands, and it is connected to the creek by a ditch. No stream processes were restored during this habitat restoration (Table 1).

EKLUTNA RIVER

The Eklutna River study site was located on the lower Eklutna River, 43.5 km north of Anchorage, Alaska (Figure 1). This watershed encompasses 277 km^2 (USGS 2004). The river is glacially fed, and it flows 35.4 km from the glacier through Eklutna Lake to Knik Arm in Cook Inlet. Large quantities of water are diverted to provide drinking water and hydroelectric power for the Municipality of Anchorage (Simonds 1995). As a result, the Eklutna River has minimal water flow, limiting available fish habitats in Eklutna Lake and the upper Eklutna River (Lamoreaux pers. comm.).

Today, the major source of water for the lower Eklutna River is Thunderbird Creek, which is a small clear water tributary stream that flows into the river approximately 4.2 km upstream from the mouth (Lamoreaux pers. comm.). A USGS gauging station located at the Old Glenn Highway Bridge recorded river flow from 2002-2005 (USGS 2004). River flow peaked during the summer months, ranging from 100 cfs in 2002 to 250 cfs in 2005. Average high flow during this four year period occurred in June, with an average flow of approximately 120 cfs. Low flow occurred during the winter months with water flow dropping below 50 cfs (USGS 2004). Precipitation in this watershed peaks in September, with an average annual precipitation of 45.9 cm (WRCC 2010).

In addition to flow regime alteration, the Eklutna River has been modified for railroad and road construction purposes, and it has been extensively gravel mined. The mouth of the river has been moved at least five times for gravel extraction projects (Lamoreaux pers. comm.). These river alterations, combined with the reduction of water flow, have impacted salmon production in the river. Before river alteration began in the 1920s, the Eklutna River was a very productive salmon stream, supporting all five species of Pacific salmon plus Dolly Varden; as a result of these alterations, the Eklutna River became a degraded stream supporting minimal salmon runs (Lamoreaux pers. comm.).

In an effort to increase salmon habitat and help restore the fishery for subsistence use by the Native Village of Eklutna, a series of three, interconnected ponds was created in the 1980s in an old gravel pit located 1.2 river km from the river's mouth on Cook Inlet. The gravel pit was connected to the main-stem Eklutna River via an artificial channel (Lamoreaux pers. comm.), which was inexpensive to construct (Table 1). While providing off-channel habitat, this project did not restore river processes (Table 1). The three ponds and the main-stem Eklutna River up to the Old Glenn Highway Bridge were examined during this study.

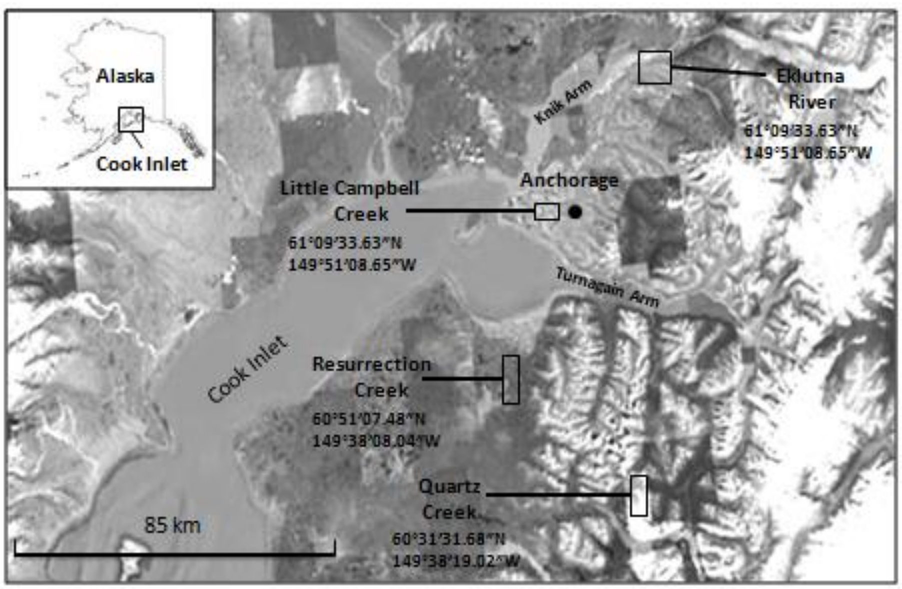

Figure 1: Map showing the locations of Resurrection Creek, Quartz Creek, Little Campbell Creek, and Eklutna River study sites in southcentral Alaska.

Table 1: Summary of the key components of the four restoration projects evaluated in this study.

Restoration Site	Type of Restoration	Pond Size	River Processes Restored	Project Cost
Resurrection Creek	4 ponds, 1 side-channel, main-stem	1,000– 4,000 m²	Yes	$1.7 million
Quartz Creek	1 pond and outflow channel	34,398 m²	No	Unknown
North Fork LCC	1 alcove	250 m²	No	$35,000 + $65,000 in donated services
Eklutna River	3 interconnected ponds	1,086- 6,153 m²	No	Minimal cost, undocumented

Thesis Overview/ Thesis Questions

In this thesis, I examine the four different off-channel stream restoration projects discussed above. The purpose of this study was to determine the success of each restoration project by monitoring if and how these artificial habitats are utilized by juvenile coho salmon on a seasonal basis. I conducted the study from May through September 2010. My main goals were to answer the following questions: 1) are the restored off-channel habitats utilized by coho salmon; 2) is relative abundance, as indexed by catch per unit effort (CPUE), higher in off-channel habitats relative to neighboring stream segments; 3) does relative abundance in the two habitat types change seasonally; 4) is water quality in the off-channel habitats within the established standards for Alaskan anadromous fish streams; and 5) are the physical habitat characteristics in the off-channel habitats adequate for rearing juvenile coho salmon?

This thesis is divided into four chapters, including this introduction. In the second chapter, I provide a qualitative evaluation of salmonid use of the off-channel habitats located at Resurrection Creek, Quartz Creek, and Little Campbell Creek. A quantitative evaluation of these habitats was not possible because I caught insufficient numbers of coho salmon in the off-channel habitats at these locations.

In the third chapter of this thesis, I provide a quantitative analysis of the off-channel habitats located on the Eklutna River. I was able to perform a quantitative analysis at the Eklutna River study site because there were sufficient numbers of coho salmon present in the off-channel habitat. In this part of the study I address questions one through five above. In addition, I included a population structure analysis study to address questions that arose during field sampling at this location. I address the following questions in the population structure analysis: 1) what is the population estimate for juvenile coho salmon in the lower Eklutna River Pond; 2) are there differences in the age class structure of coho salmon rearing in the ponds relative to the stream; and 3) does water temperature affect coho salmon distribution within the three ponds?

In the fourth chapter, I discuss the implications that the results of this research have for the development and implementation of future, off-channel, salmon habitat restoration projects, and provide information about the types of stream restoration that are the most beneficial for coho salmon.

Chapter 2: Evaluation of Off-channel Salmon Habitats at Resurrection Creek, Quartz Creek, and Little Campbell Creek, Alaska

In this thesis chapter I will examine three off-channel habitat restorations, located on Resurrection Creek, Quartz Creek, and Little Campbell Creek. My purpose in this chapter is to evaluate the off-channel habitats in which coho salmon were not caught or that had minimal coho use throughout the study period. Determining why certain habitats were not utilized by coho salmon yields valuable information that could be used to improve the design, function, and management of existing and future off-channel habitat restorations. The thesis questions addressed in this chapter include: 1) are the three restored off-channel habitats utilized by juvenile coho salmon; 2) in habitats with coho salmon present, is catch per unit effort (CPUE) higher in off-channel habitats relative to neighboring stream segments; 3) does relative abundance in the off-channel and main-stem habitat vary seasonally; 4) does water quality in each off-channel habitat meet the state standards for anadromous fish rearing (ADEC 2009); and 5) are the physical habitat characteristics in each off-channel habitat adequate for juvenile salmon rearing?

METHODS

Field Sampling

I measured CPUE, water quality, and physical habitat characteristics at all three study sites. While water quality measurements and characterization of physical habitat were the same at all three sites, trapping methods were slightly different for each study site because the off-channel ponds and main-stem habitats at each study site were not the same size, and they had different types of habitat.

Trapping

RESURRECTION CREEK

The trapping study of Resurrection Creek was conducted once a month between May and September 2010. Four off-channel ponds, one side-channel connecting the ponds, and three main-stem sites (two pools and one alcove) located on the western side of the Resurrection Creek stream restoration were examined (Figure 2). Three of the four ponds are connected via a flowing side-channel during high flow. The fourth pond is not connected to the lower three ponds or surface water from the main-stem and it was not functioning as designed. The ponds range in size from the smallest (Pond 1) at approximately 1000 m^2 to the largest (Pond 2) over 4000 m^2.

Gee 1/4" mesh minnow traps baited with salmon roe were used in May and June. However, young-of-year salmon can escape from traps with 1/4" wire mesh. Since the majority of fish at this location were young-of-year, trap size was reduced to 1/8" mesh for the July-September samplings. During the initial May sampling, the trap soak time was one hour, but since there were no fish in the traps after the first hour, the traps were redeployed for an additional hour. Traps were set for two hours in June as well. Reducing the trap size to 1/8" mesh in July resolved the fish capture issues, and the trap soak time was reduced back to one hour for the remainder of the study. Since no coho salmon were caught using four traps per pond in May, the number of traps set in June was increased to six in Ponds 2, 3, and 4. The number of traps set in these ponds was reduced back to four in July. No traps were set in the side-channel in May because the channel had no water (Table 2). Off-channel pond traps were set equidistantly apart near the shore in shallow water (<1 m). Main-stem channel traps were set close to the bank in pool habitats with slower moving water and large woody debris cover because these habitats are preferred by young-of-year coho salmon (Magnus et al. 2006).

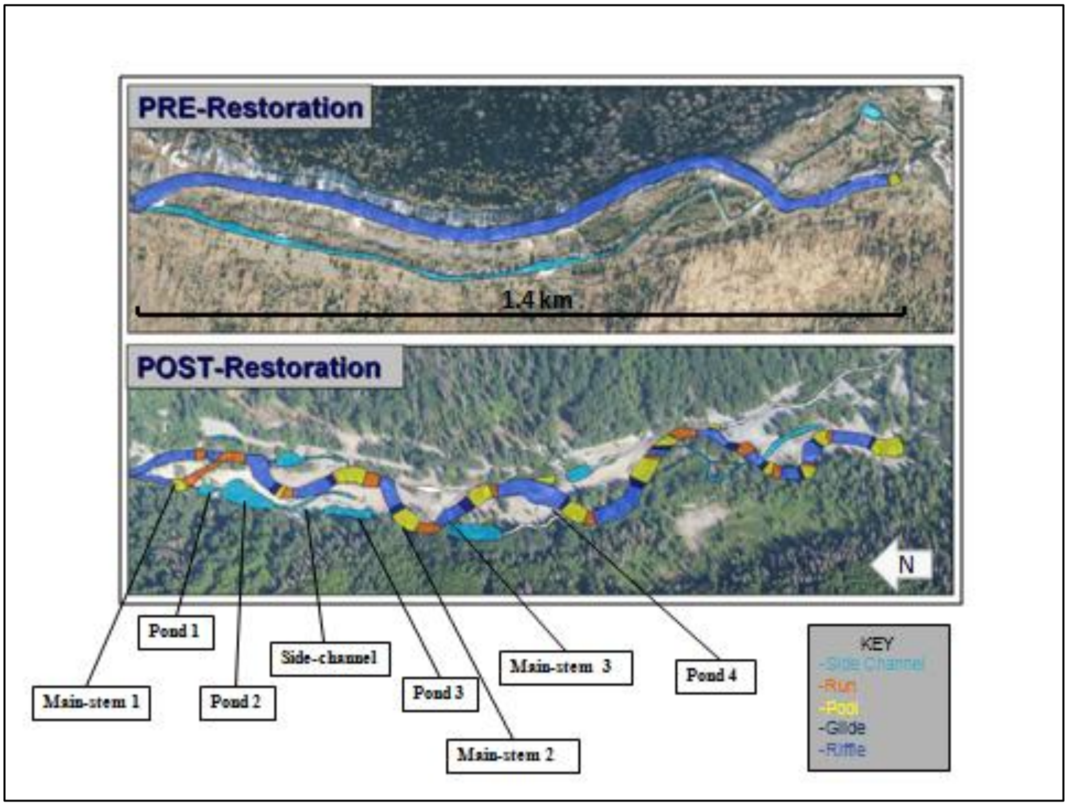

Figure 2: River habitat types present before and after the stream restoration at Resurrection Creek (MacFarlane 2006). The four off-channel ponds, one side-channel connecting the ponds, and three main-stem habitats (two pools and one alcove) sampled in this thesis are labeled.

Table 2: The number of traps set at each sampling location on Resurrection Creek and the trap soak time in minutes for the May-September 2010 CPUE sampling.

Month	Pond 1	Pond 2	Pond 3	Pond 4	Main-stem	Side-channel	Soak Time
May 17	4	4	4	4	3	0	120
June 12	3	6	6	6	3	1	120
July 10	3	4	4	4	3	1	60
Aug. 14	3	4	4	4	3	1	60
Sept. 11	3	4	4	4	3	1	60

QUARTZ CREEK

The study of Quartz Creek Pond was conducted once in May and once in August 2010. One off-channel pond and an artificial stream channel were examined (Figure 3). Minnow trapping was conducted in the pond and its outflow stream channel in May. Ten baited Gee 1/4" mesh minnow traps were set equidistantly apart along each shoreline of the pond in depths less than one meter. An additional eight traps were set in the outflow stream channel, evenly distributed between the pond and culvert located under the Sterling Highway. All traps soaked for one hour. The site was revisited in August 2010, but only physical habitat observations were made because the pond was completely disconnected from the artificial stream channel, prohibiting fish movement into the habitat.

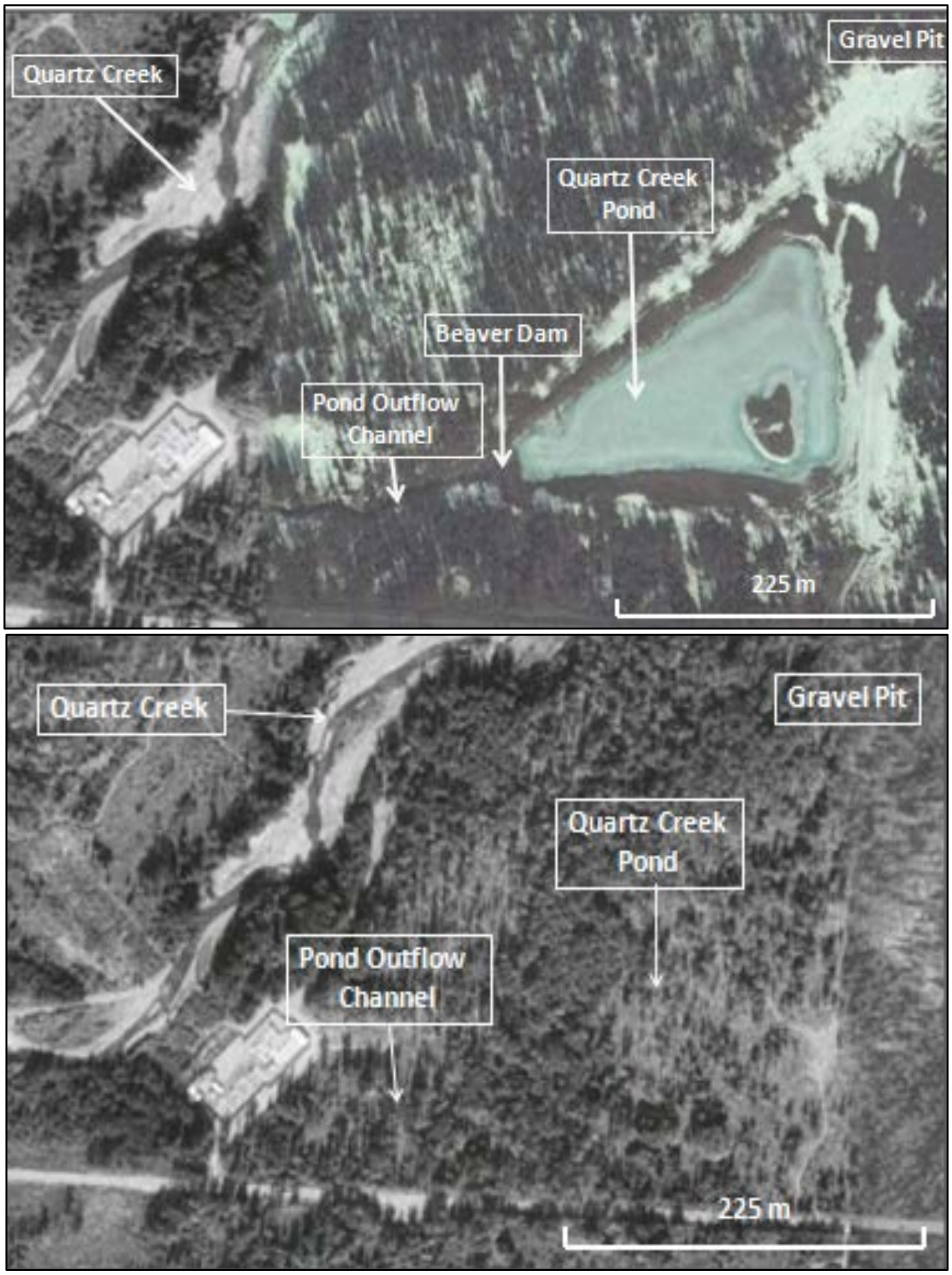

Figure 3: Areal imagery showing the Quartz Creek pond and outflow channel prior to the restoration project (1997) and after the restoration (2004). The pond and stream channel were not present prior to the restoration.

LITTLE CAMPBELL CREEK

The study of the LCC alcove was conducted in October 2009, and in April, May, and August of 2010. One off-channel alcove and two main-stem sites located directly above and below the alcove were examined (Figure 4). The alcove is approximately 250 m² with four vegetated islands in the middle. Minnow trapping was conducted in the alcove and main-stem channel of the North Fork of LCC in October 2009 and May 2010. The alcove was checked in April 2010, but it was frozen almost to the substrate and there was not enough water to deploy minnow traps. The site was revisited in August 2010, and physical habitat observations were made. No minnow traps were deployed at this time because the water was not deep enough to submerge the traps. In both October and May, six Gee 1/4" wire mesh minnow traps baited with salmon roe were deployed equidistantly apart in the alcove. An additional 12 traps were deployed in the main-stem channel, with six traps above and six traps below the alcove. Traps soaked for 30 minutes.

Figure 4: LCC Alcove after construction in July 2007 and a year later in 2008 (Anchorage Waterways Council 2008).

Relative abundance (CPUE) calculation

At each study site where fish were captured, they were placed in five gallon buckets, identified to species, and measured to fork length. The total number of fish caught in each trap, the number of traps deployed, and the trap soak time were recorded. The CPUE was calculated using the following formula:

CPUE= ((C/T)/S)*60,

where C is number of fish caught, T is number of minnow traps set, and S is soak time in minutes. The total is multiplied by 60 to calculate the number of fish caught per trap hour (Proctor 2003).

For the Resurrection Creek study site, non-parametric Kruskal-Wallis analysis of variance tests (ANOVA) were used to compare relative abundance (CPUE) across six different habitats (Ponds 1, 2, 3, 4; main-stem; side-channel) in July, August, and September. May and June CPUE data were not included in the ANOVAs because a different trap mesh size was used during those months. The alpha level was corrected by dividing 0.05 by the number of comparisons that were made, setting the adjusted alpha level at 0.02. Multiple comparison post-hoc tests were used to determine which habitats significantly differed. Non-parametric tests were used because the data violated the assumptions of equal variance and normality. The analysis was conducted using the software program PASW 18 (IBM Corporation, Somers, NY).

Water Quality

At each of the three study sites, a set of water quality measurements was taken during each minnow trapping event: temperature (ºC), specific conductance (SPC, µS), dissolved oxygen (DO, mg/L), and pH. Measurements were done from May through September 2010 at Resurrection Creek, in May 2010 at Quartz Creek, and in October 2009 and May 2010 at LCC.

Water temperature and SPC were measured using a YSI EC300 portable conductivity, temperature, and salinity meter. DO was measured using a YSI DO200 portable DO/Temperature meter, and pH was measured using a Hach EC20 portable pH meter. All meters were cleaned and calibrated prior to each field day. Additionally, water temperature in the LCC alcove and in the main-stem adjacent to the alcove was measured hourly from May to October 2010 using two TidbiT V2 temperature loggers that were attached to the stream substrate. One temperature logger was placed in the middle of the alcove and the other was placed in the main-stem adjacent to the alcove.

Five consecutive measurements were taken for each water quality parameter directly above the outflow channel for each pond. If pond inflow channels were present, an additional five measurements were taken directly below the inflow channel. The five measurements were evenly spaced across the inflow and outflow channels so the measurements spanned the entire width of each channel. Water quality parameters were measured every 0.3-0.6 m in a cross-section of the main-stem channel for the Quartz Creek and LCC sites. Swift water flow at Resurrection Creek prevented measurement along a main-stem cross-section. Instead, water quality in the main-stem was measured in five places along the shoreline where each trap was set. Water quality was measured in five places in a side-channel pool from June-September at this location as well. Measurements were not taken in May because there was no water in the side-channel. All measurements were collected in the middle of the water column halfway between the surface and substrate to ensure that the water was well mixed. Measurements were taken immediately after minnow traps were deployed.

For each habitat type sampled, the consecutive temperature, SPC, DO, and pH measurements were averaged to yield a mean value for each month. These mean values for each month's sampling were averaged to yield an overall mean value and range of means over the entire study period. The range of each water quality parameter was compared to the Alaska water quality standards for anadromous fish streams to determine if water quality in the off-channel habitats exceeded the accepted limits for rearing andromous fish (ADEC 2009). The LCC temperature data from the loggers was used to determine the average and range of temperatures in the alcove from May 5 to October 7, 2010. The average temperature, range, and the total number of days when temperatures exceeded the recommended 15ºC limit (ADEC 2009) are reported.

Physical Habitat

Physical habitat observations were made for the ponds and main-stem channel using an aquatic habitat assessment sheet (Appendix A; USDA 1998). The type and amount of inorganic and organic components present in the substrate were approximated. Turbidity, or water clarity, was ranked on a scale of one to five (one denoting clear and five turbid; Appendix A). The predominant type of vegetation and the percent canopy cover within an 18 m buffer of the ponds were estimated and type and approximate percent coverage of aquatic vegetation present in each pond were noted. The percentage of the pond's surface covered by large woody debris was approximated as well. Water depth was measured around the shorelines and depth in the middle of the ponds was estimated. Additional observations were made about the type, gradient, depth, and water flow in the pond inlets and outlets. The inlet and outlet channels were observed during each sampling to determine if fish were moving though the pond inlet and outlet channels at the time of sampling. Photographs were taken during each site visit to document physical habitat changes.

RESULTS

Coho salmon were only caught during the July-September samplings at Resurrection Creek, and no coho salmon were caught in the Quartz Creek and Little Campbell Creek off-channel habitats during this study. Thus, the evaluation of these study sites is based mostly on qualitative observations.

RESURRECTION CREEK

Relative Abundance

CPUE was low in all habitats in July, with catches only in the main-stem and side-channel habitats. CPUE was highest in the main-stem and side-channel habitats in August. In September, CPUE was highest in the off-channel ponds with Pond 3 accounting for 62.7% of the catch. Coho salmon caught in the ponds and main-stem were small, with 86.8% of the catch ranging from 40-65 mm in fork length.

There were significant differences in CPUE across the six habitats in July, August, and September. In July, CPUE was significantly higher in the main-stem habitats than the off-channel habitats ($H(5)= 16.87$, $p= 0.01$); Figure 5). In August, CPUE in the side-channel was significantly higher than CPUE in the main-stem and pond habitats ($H(5)= 14.16$, $p= 0.01$). In September, Pond 3 had a significantly higher CPUE than all other habitats ($H(5)= 12.95$, $p= 0.02$; Figure 5).

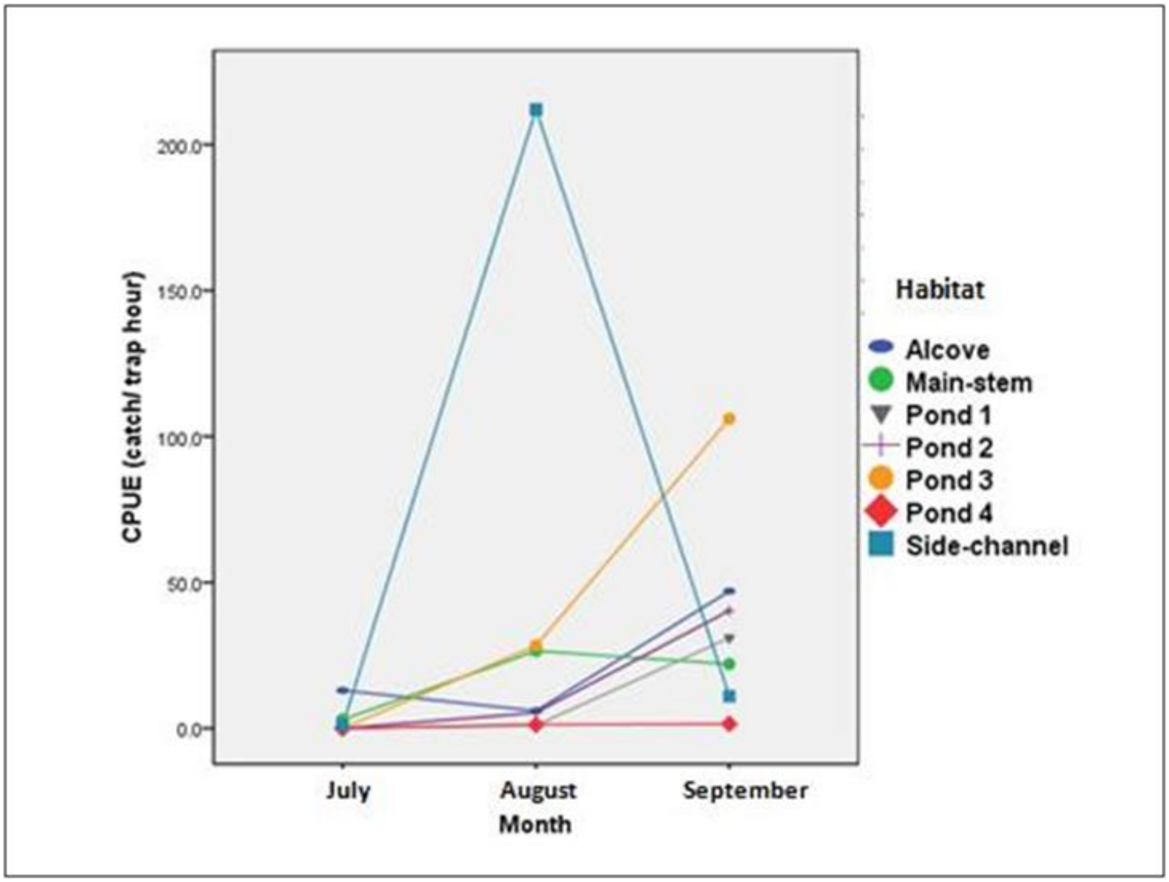

Figure 5: Coho salmon CPUE in Resurrection Creek in July, August, and September for the four ponds, three main-stem, and one side-channel habitat.

Water Quality

The average temperature for the ponds, main-stem, and side-channel habitats ranged from 7.0 to 7.5ºC (Table 3), which was well below the established maximum for salmonid rearing (<15ºC; ADEC 2009). Maximum recorded temperature was 9.7ºC. DO was also within established guidelines (7-17 mg/L; ADEC 2009) in the pond, side-channel, and main-stem habitats. DO was the lowest in Pond 4, 11.1 mg/L, and highest, 14.9 mg/L in the main-stem alcove habitat (Table 3). pH was below the lower water quality standard of 6.5 in Ponds 2 and 3 and in the main-stem alcove, with values between 6.1 and 6.4. Conductivity was low, and it did not vary much among habitats, ranging from 84.8 to 137.5 µS.

Table 3: Water quality results for the ponds, main-stem, and side-channel habitats in Resurrection Creek. The average and range for each water quality parameter during the entire study period are reported by habitat.

Habitat	**Temperature (°C)**		**Dissolved Oxygen (mg/L)**		**pH**		**Conductivity (µS)**	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
Pond 1	7.0	5.0-8.4	12.9	11.5-14.5	6.9	6.7-7.2	97.7	85.2-113.4
Pond 2	7.2	5.1-8.9	13.2	11.5-14.7	6.7	6.1-7.0	95.4	85.5-105.6
Pond 3	7.1	5.4-8.7	13.8	13.3-14.3	6.7	6.2-7.2	91.6	85.6-101.7
Pond 4	7.5	4.8-9.7	11.1	10.4-11.7	7.0	6.6-7.3	129.7	115.0-137.5
Side-channel	7.4	7.0-8.8	13.4	13.1-13.8	6.6	6.1-7.2	96.7	86.5- 107.8
Main-stem	7.5	5.3-8.7	14.2	13.8-14.8	6.7	6.5-6.9	98.2	87.0-114.7
Main-stem Alcove	7.1	5.5-9.2	14.9	13.9-15.2	6.8	6.4-7.2	90.0	84.8-95.6

Physical Habitat

Substrate consisted of cobble and boulders. Water depths were approximately one meter close to the pond shorelines with depths increasing in the middle of the ponds when water flow was high in June and July. Water depth changed substantially with flow in the main-stem, reducing the amount of wetted pond and side-channel habitat available as well as the water depth in the ponds during low flow periods (May, August, September; Appendix B.1-B.6). Water levels in the main-stem were much lower in May and September (Appendix B.7-B.9). The water inflow and outflow channels were steep, shallow, and narrow. They had swift water flow over a cobble/boulder substrate during high flow samplings (Appendix B.10). During low flow samplings, they were impounded by boulders, cobble, and woody debris, blocking fish acess to the off-channel ponds (Appendix B.11). No fish were observed in the inflow and outflow channels near the ponds. Ponds 1, 2, and 3 were not turbid and the water was clear down to the substrate during each sampling event from May-September. Pond 4, which had no apparent surface inflow or outflow, had turbid water during the June sampling. Shoreline vegetation was present along the western shoreline of each pond, and it consisted of cottonwoods (*Populus trichocarpa*), birch (*Betula papyrifera*), and white spruce (*Picea glauca*). The eastern shoreline of the ponds was dominated by grasses. Canopy cover was limited, with the majority of each pond exposed to direct sunlight. Aquatic vegetation was present in the shallower parts of the ponds (<1 m), with deeper pond segments (>2 m) free of aquatic vegetation. All four ponds had large woody debris.

QUARTZ CREEK

Relative Abundance

No coho salmon were caught in the pond or the outflow stream channel during the May 2010 sampling (CPUE= 0.0). Small, young-of-year coho salmon were seen surrounding the lower trap in the outflow channel by the Sterling Highway culvert. In August, juvenile salmonids were trapped in exposed step pools in the outflow stream channel below the pond. No fish were observed in the pond.

Water Quality

During the May sampling, water temperature in the pond outflow channel above the beaver dam averaged 10.0ºC. Water in the outlet stream channel was colder, with temperatures averaging 1.2ºC. DO levels were sufficient (ADEC 2009), ranging between 12.7 and 13.6 mg/L. The pH level was lower than the lower water quality standard (6.5), ranging from 6.2-6.4. Conductivity was low, ranging from 99.8 µS in the pond to 110.1 µS in the stream outlet channel (Table 4).

Table 4: Water quality measurement for the pond and stream outlet channel in Quartz Creek in May 2010.

Location	**Temperature (°C)**		**Dissolved Oxygen (mg/L)**		**pH**		**Conductivity (µS)**	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
Pond	10.0	9.9-10.2	13.3	12.7-13.6	6.3	6.2-6.4	101.1	99.8-102.3
Outlet Stream	1.2	1.1-1.3	15.5	14.8-15.7	7.4	7.3-7.5	107.7	104.3-110.1

Physical Habitat

Water depths exceeded two meters, and the water was clear down to the substrate. There was no inflow channel or source of surface water input (Appendix B.12). The pond and outflow stream channel were groundwater fed. Water flow from the pond to the stream channel was severely blocked by a beaver dam, which exposed a series of 13 step pools in the outflow stream channel immediately below the pond, impairing water flow and pond connectivity (Appendix B.13). In August, the pond was completely separated from its outflow channel and the step pools were isolated from one another and disconnected from the stream (Appendix B.14). Stream flow regenerated approximately 30 m downstream from the pond, where groundwater seepage formed a small stream. The artificial stream channel was meandering and had large woody debris, root wads, and boulders. Shoreline pond vegetation consisted of grasses and sedges, with alders (*Alnus spp.)* growing further away from the shoreline. There was little to no canopy cover to provide shade to the pond. No aquatic vegetation was observed in the pond. Large woody debris was numerous within two meters of the pond shoreline.

LITTLE CAMPBELL CREEK

Relative Abundance

No coho salmon were caught in the off-channel alcove (CPUE= 0.0) during the October and May samplings. A total of seven coho salmon (CPUE= 2.3) were caught in the creek above the alcove, and two (CPUE= 0.7) below the alcove in early October 2009. Coho salmon were not captured in late October. One coho salmon was caught above the alcove in early May (CPUE= 0.3).

Water Quality

Water quality in the off-channel alcove did not meet state standards for anadromous fish rearing (Table 5). From May 5 to October 7, 2010, the average alcove temperature was 12.4ºC. Water temperatures during this period reached a high of 23.4ºC on July 22, and they exceeded the 15ºC mark for five or more hours per day for 76 of the 150 days measured. Temperatures in the main-stem did not exceed 15ºC at any point, and the average temperature was 9.7ºC. DO levels in the alcove were very low as well (<7 mg/L), with concentrations ranging from 0.8-2.4 mg/L in October, and 3.7-6.2 mg/L in May. The pH level was within the guidelines (ADEC 2009), ranging from 6.9-7.1. Conductivity ranged from 322.4-365.6 µS.

Table 5: Water quality averages and ranges for the alcove and main-stem of the North Fork of the LCC. The temperature average and range is from May 5 to October 7, 2010. The DO, pH, and conductivity averages and ranges are from the October 2009 and May 2010 sampling events only.

Location	**Temperature (ºC)**		**Dissolved Oxygen (mg/L)**		**pH**		**Conductivity (µS)**	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
Alcove	12.4	2.6-23.4	3.8	0.8-6.2	7.0	6.8-7.1	348.7	322.4-365.6
Stream	9.7	2.2-14.5	12.3	11.9-13.5	7.7	7.6-7.9	312.3	308.1-315.3

Physical Habitat

The alcove consisted of a small channel of water (<1m wide) wrapping around four vegetated islands in the middle of the alcove. Water depths were shallow (<0.2 m), providing little wetted habitat. In October, May, and August water clarity was reduced by an oily sheen that covered the water's surface along the back side of the alcove nearest the road, and by suspended organic solids (Appendix B.15). There was no surface inflow into the alcove, and the outflow channel was narrow (<0.4 m) and shallow (0.06 m). Shoreline vegetation consisted of grasses and sedges. Four vegetated islands located in the alcove, and a steep bank along the southern alcove shoreline provided additional shade. Aquatic vegetation and algae were numerous, and there was no large woody debris.

DISCUSSION

RESURRECTION CREEK

All four ponds studied at Resurrection Creek supported juvenile coho salmon at some point during this study. The lack of coho salmon caught early in the year may be attributable to trapping error. Most of the fish observed in the ponds and main-stem at this time were young-of-year too small for 1/4" wire mesh traps. A 1/4" wire mesh successfully traps fish larger than 50 mm (Swales 1987). Since coho salmon in Resurrection Creek migrate at age 1 (USDA Forest Service 2010) and the fish tend to be small, the 1/4" mesh minnow traps, which are biased against small individuals, likely missed the young-of-year and small age 1 fish that predominate in this stream system.

The increase in CPUE in the ponds and side-channel habitats in August and September may be explained by seasonal coho salmon movement into off-channel habitats. Coho salmon typically move into off-channel habitats to over-winter in late-summer and fall with freshets, which increase water flow and decrease water temperatures (Bramblett et al. 2002). Coho salmon may have moved into off-channel habitats in July and August before the water levels dropped and reduced fish access to the ponds. Additionally, decreasing water flow and low water levels reduced the amount of wetted habitat in Ponds 1, 2, and 3 by almost half in September. The smaller pond sizes likely forced fish into closer proximities, increasing fish densities. Thus, both seasonal coho salmon movements into off-channel habitats and reductions in pond size could have contributed to the increase in CPUE in off-channel habitats from July-September.

Although water quality in the ponds was within the guidelines for Alaskan anadromous fish streams (ADEC 2009), and there was sufficient habitat present to support juvenile fish for the duration of this study, access to the pond habitats was limited by poorly defined access channels that were disconnected from the main-stem. Flowing surface water inlet and outlet channels were not present when the sites were sampled during low flow conditions (May, August, and September), impairing fish movement in and out of these habitats. Pond 3 was the only pond with a consistently flowing input channel from May-September, which may explain why CPUE was higher in this pond than the other three ponds. Water flow into Pond 2 depended on sufficient outflow from Pond 3, and flow into Pond 1 depended on outflow from Pond 2. When flow dropped in the main-stem in spring and fall, surface water did not move through the pond system, and the ponds were disconnected from each other and the main-stem channel, eliminating fish access to the habitats. Since water flow in this system is fed by snowmelt, the best access to the off-channel pond and side-channel habitats occurred in June and July when snowmelt was highest.

Fish access to the ponds may be limited by the type of inlet and outlet channels as well. When flowing, the inlets and outlets are shallow (<0.15 m), narrow (ranging from 0.3-1.8 m), and very steep with vertical drops into the ponds. Flow into the ponds, especially Pond 3, is very swift. Swift water flow and turbulent flow near culvert outlets impairs the ability of coho salmon to maintain resting positions (Kahler and Quinn 1998). Additionally, coho salmon did not pass through culverts when water flow was greater than 0.65 cfs at steep gradients (>10%; Kahler and Quinn 1998). The pond inlet and outlet channels are similar to steep gradient culverts; thus, they may affect fish movement in and out of the ponds. Since stream-pond connectivity is limited by the reduction of water flow and poorly defined access channels, fish can become stranded in the disconnected off-channel habitats during low flow periods. Thus, the coho salmon observed in the ponds in August and September likely remain in the ponds until winter floods or summer snowmelts increase the flow in the main-stem reconnecting the off-channel habitats, and allowing the fish to escape.

The changes in water flow alter the water levels in the ponds as well. The water level dropped by approximately 1.8-2.4 m from July to September, reducing the amount of wetted habitat available in the lower three ponds. The reduction in wetted pond habitat pushes fish into closer proximity, potentially increasing competition for habitat and food resources. The low water levels stranded coho salmon in a shallow pool in the side-channel connecting Pond 2 and Pond 3 as well. Coho salmon stuck in this pool may be more susceptible to predation because the pool is shallow and it does not provide protective cover.

In order for these ponds to reach their full potential as salmonid rearing habitats, it is necessary to construct clearly defined inlet and outlet channels that maintain their connection to the main-stem throughout the year. Connecting each pond directly to surface water flow from the main-stem, rather than connecting a series of ponds together, would help ensure sufficient year-round flow and access to the ponds. Since coho salmon typically use off-channel habitats in fall and winter (Swales and Levings 1989), improving year-round access to these ponds is essential to maximizing the productive capacity of the ponds. Having a consistent surface water input flow improves water quality as well. Surface water inputs bring cooler, well oxygenated stream water into the pond system, which helps buffer pond temperatures and increase DO necessary for fish respiration (Bryant 1988).

Artificial, off-channel habitats should be designed to maintain connectivity during low flow periods to maximize coho salmon utilization of the habitats. In practice, it is difficult to account for unexpected shifts in the river's flow path and flow regime. Thus, it may be necessary to monitor the restoration for several years after completion to determine how natural changes in the river's flow regime are impacting pond connectivity. Additionally, constructing new inlet and outlet channels, or modifying the current channels, may be necessary to improve fish access in habitats that are not functioning as designed.

QUARTZ CREEK

No fish were caught or observed in the Quartz Creek pond during this study. The absence of fish in this pond is likely due to a complete blockage of the pond's outflow channel by a beaver dam, which interferes with fish access. The blockage is compounded by a series of 13 step pools that were designed to control water flow from the pond. The step pools were constructed from large rocks, which are now exposed, creating additional barriers to fish passage.

In order for this habitat to function as a rearing habitat for salmonids, the connection between the pond and the stream channel must be regenerated and maintained. Keeping this habitat functioning would be difficult because it requires the removal of beavers, and constant maintenance to ensure that beavers do not re-colonize the pond. Other options for improving accessibility to this habitat are limited because the habitat is far away from the stable flow of Quartz Creek. Ideally, this habitat needs multiple connections to a well established, main-stem channel, and a flowing input channel to push water through the pond. However, since the pond is far away from an established stream, there is no option to create additional access channels and a flowing water input channel.

Some of the physical features of this pond are not ideal for rearing coho salmon. Water depth exceeds the preferred depths of one to two meters for rearing coho salmon throughout much of the pond. The lack of a surface water input could cause reduced DO levels, especially during the winter when ice covers the pond. Shoreline vegetation and canopy cover are lacking, exposing the pond to direct sunlight. The lack of vegetative cover may increase mid-summer water temperatures above the tolerance of rearing juvenile coho salmon. Constructing a smaller, shallower pond with sufficient vegetative cover along the shorelines may create a more favorable habitat for rearing coho salmon.

LITTLE CAMPBELL CREEK

No fish were caught in the off-channel alcove in the North Fork of the LCC during this study, but juvenile coho salmon and dolly varden were caught in the main-stem immediately above and below the alcove. During prior research, four juvenile coho salmon were caught in the alcove after high flow rain events in September (Ammann pers. comm.), indicating that very small numbers of coho salmon likely utilize this habitat when water flow and turbidity increase in the main-stem.

The low water quality measured in the alcove is likely related to the lack of surface water flow and shallow depth. The major source of water in the alcove is groundwater, which can have low DO levels. Thick aquatic vegetation may contribute to the exceptionally low DO levels measured in fall, because microbes utilize DO and release carbon dioxide when breaking down aquatic plants, reducing the amount of DO available in the water (Kramer 1987). An oily sheen was present on the water at the back end of the alcove nearest the road, indicating that runoff from the street or contaminated groundwater may be impairing water quality in the alcove. The shallow depth and the lack of surface water flow likely contribute to the high summer water temperatures. The shallow depths do not provide adequate habitat and cover, making fish in the habitat more susceptible to predation as well.

Access to the alcove is limited by a poorly defined connection to the stream. The connecting channel is too narrow and shallow to allow appropriate fish movement in and out of the habitat. The access channel needs to be widened and deepened. Fish access to the alcove and water quality could be improved if surface water from the creek was diverted to flow through the alcove, bringing a fresh supply of cold, oxygenated water into the alcove. Surface water flow would buffer water temperatures and increase DO levels. Deepening the alcove to 1-1.5 m would provide more wetted habitat and protective cover for coho salmon, and make the habitat usable during the winter months. Currently, the water is too shallow, and it freezes to the bottom during winter.

CONCLUSION

The problems with the off-channel habitats at the Resurrection Creek, Quartz Creek, and LCC study sites yield valuable information about the design and function of off-channel habitats, which can be applied to future restoration designs. Future off-channel restoration projects and completed restorations that are not functioning as fish habitats should implement the following structural changes to improve water quality and increase fish utilization of the habitats: 1) create year-round surface water flow through off-channel habitats to improve water quality and fish access to the habitats; 2) construct multiple, deep and wide pond inlet and outlet access channels with year-round connections to the main-stem to prevent fish stranding and improve fish access; and 3) increase mid-pond depths to 1.4-2 m and the amount of riparian vegetation along the pond shorelines to help regulate pond temperatures. Including these features in off-channel habitat designs has the potential to increase use of artificial off-channel habitats by juvenile coho salmon.

Chapter 3: Evaluation of Off-channel Salmon Habitats on the Eklutna River, Alaska

In this thesis chapter I will examine the Eklutna River off-channel habitat restoration. My purpose in this chapter is to examine an off-channel habitat restoration that was functioning as a coho salmon habitat throughout the entire study period. Evaluating functioning artificial habitats, and determining how they are used seasonally by coho salmon, can provide information to improve current restorations that are not functioning and aid in the design of future restorations. This chapter addresses the same thesis questions that were assessed in Chapter 2. In addition, a study on coho salmon population structure was included in this chapter to address the following questions that arose during field sampling: 1) what is the population estimate for juvenile coho salmon in the lower Eklutna River Pond (Pond 1); 2) are there differences in the age class structure of coho salmon rearing in the ponds relative to the stream; and 3) does the water temperature affect coho salmon relative abundance within the three ponds on the Eklutna River?

METHODS

Field Sampling

I measured CPUE, water quality (temperature, conductivity, DO, and pH), and physical habitat characteristics in the three ponds and main-stem of the Eklutna River. Additionally, to investigate coho salmon population structure in the Eklutna River, I used a Peterson mark-recapture method to determine the population estimate in Pond 1, and I collected scales from coho salmon in the three ponds and main-stem in September to determine coho salmon ages. Finally, in addition to the temperature measurements in pond inlets and outlets, I measured water temperature at each trap location throughout the three ponds in August and September.

Trapping

The Eklutna River trapping study was conducted from May-September 2010. Specifically, three interconnected ponds and a main-stem site located adjacent to the ponds were sampled during the study (Figure 6). Pond 1 was the largest at 6,153 m^2. Pond 2 was 6,022 m^2, and Pond 3 was the smallest at 1,086 m^2.

Gee 1/4” mesh minnow traps baited with salmon roe were used. The trap soak time was standardized at one hour throughout the duration of the study (Swales 1987). In May and June, traps were set approximately 30 m apart along two transects within one to five meters of each pond shoreline in depths less than one meter (Swales and Levings 1989). For the July-September sampling events, extra traps were set along a line transect in the middle of each pond approximately 30 m apart. In Pond 2, four shoreline traps were moved to the mid-pond transect. In Pond 3, two traps were moved to the mid-pond transect. In Pond 1, four new traps were set along a mid-pond transect, and four traps were added to the lower section of the pond (Table 6). It was necessary to move traps to the middle of the ponds because aquatic vegetation overtook the shoreline habitats, and the fish concentrated in the middle of the ponds and in the lower part of Pond 1 after the May sampling. Thus, a more extensive evaluation of mid-pond and lower Pond 1 habitats was necessary. Minnow traps were placed in the main-stem immediately above Pond 1 as well. Traps were set approximately 30 m apart along each stream bank.

Figure 6: Aerial imagery showing the three ponds and main-stem sampling location on the Eklutna River.

Table 6: The number of traps set in each habitat type on the Eklutna River during each month of CPUE sampling in 2010.

Month	**Pond 1**	**Pond 2**	**Pond 3**	**Main-stem**
May 18	8	12	4	8
June 17	8	12	4	8
July 12	16	12	4	8
Aug. 17	16	12	4	8
Sept. 18	16	12	4	8

Relative abundance (CPUE) calculation

Relative abundance was calculated using the CPUE formula given in Chapter 2 (p. 22). Non-parametric Kruskal-Wallis ANOVAs were used to compare relative abundance (CPUE) in the four habitats (Ponds 1, 2, and 3; main-stem) for each month from May-September. The alpha level was corrected by dividing 0.05 by the number of comparisons that were made, setting the adjusted alpha level at 0.01. Multiple comparison post-hoc tests were used to determine which habitats significantly differed.

Water Quality and Physical Habitat

Water quality (p. 22-24) and physical habitat characteristics (p. 24) were measured and analyzed using the methods described in Chapter 2.

Population Structure Analysis

Population Estimate/ Mark-recapture

A Chapman modified Peterson mark-recapture study (Lockwood and Schneider 2000) was conducted in the lower Eklutna River pond (Pond 1) on July 23, 2010. A bi-census sampling design, in which fish were marked in an initial marking session and then recaptured, was utilized (Schneider 1998). A mark-recapture was not conducted in Pond 2, Pond 3, and the main-stem channel because CPUE was low in these habitats in July, with catches less than ten coho salmon of size suitable for tagging per location.

A block net was placed at the outlet of Pond 1 to isolate the fish population and prevent any fish movement in or out of the pond system. A block net was not placed in the inlet of Pond 1, but given the low number of fish in caught in Pond 2 (8) and Pond 3 (0) in July, fish movement into these habitats from Pond 1 is unlikely. Salmon were collected for tagging using

Gee 1/4” mesh minnow traps baited with salmon roe. Eighteen traps were set approximately 20 m apart in the deeper, mid-pond and lower pond habitats that were free of aquatic vegetation. The traps were checked and emptied every 30 minutes for three hours. After capture, the salmon were anesthetized with clove oil and marked on the left adipose eyelid using a red florescent Visible Implant Elastomere (VIE). VIE tags were chosen for fish marking because the tags have high retention rates, less than 96 % after six months in salmonids (Walsh and Winkelman 2004), they do not impact fish behavior or impair growth and survival, and they are easily detected during the recapture event (Northwest Marine Technology 2006). Only coho salmon larger than 60 mm in fork length were tagged. In total, 179 coho salmon were tagged and released. The fish recovered in aerated containers prior to release, and they were redistributed evenly throughout Pond 1 to ensure remixing of the population.

The recapture event occurred two hours after the marking event was completed. The recapture was done the same day as the marking event to ensure that there was no movement of the coho salmon population in and out of the pond. The water level in the pond changes with the tides, which could allow fish to escape or enter the ponds if left overnight, violating the assumption that the population is isolated. Additionally, the block net would interfere with beaver activity in the ponds if left overnight. A large seine, approximately 14 m wide, was used to collect fish for the recapture. Using a seine for the recapture ensured that marked and unmarked fish had an equal chance of being recaptured, and it eliminated trap bias. Tows were made with the seine until ten percent (17 coho) of the tagged fish were recovered. A total of 15 tows approximately nine meters in length were made throughout the entire pond. All fish were lost during three of the tows because thick vegetation interfered with the net as it was brought ashore. All recaptured fish were identified to species, and coho salmon larger than 60 mm were evaluated for the presence or absence of VIE markings. The fish were kept in aerated containers until the completion of the recapture event, when they were returned to the pond.

The Chapman modification of the Peterson mark-recapture formula was used to calculate the population estimate for Pond 1:

$$N = \frac{(M+1)(C+1)}{(R+1)},$$

where N is the population estimate, M is the number of fish marked and released in the first sample, C is the total number of fish caught during the recapture, and R is the number of marked fish in the recapture event. The variance was calculated using the following formula:

$$\text{Variance of } N = \frac{(M+1)^2(C+1)(C-R)}{(R+1)^2(R+2)} = \frac{N^2(C-R)}{(C+1)(R+2)}$$

A Poisson distribution, which provides accurate measures of variability, was used to determine the lower and upper confidence limits. The Poisson distribution table provides lower and upper ranges for R (9.9 and 27.2), which are substituted for R in the equation $N = \frac{(M+1)(C+1)}{R+1}$ to calculate the lower and upper confidence limits (Lockwood and Schneider 2000). The population estimate, confidence limits, and standard error were reported. The density of coho salmon larger than 60 mm fork length in Pond 1 was calculated by dividing the coho salmon population estimate by the total area of the pond in m^2, and multiplying by 100 to get the number of coho salmon per 100 m^2 (unit: coho salmon/ 100 m^2).

Coho Age Structure

Observations of apparent age differences between coho salmon caught in the ponds and main-stem channel during the May-August CPUE sampling prompted further analysis of the age structure of coho salmon. Coho salmon scale samples were collected during the September CPUE sampling to determine the age structure of coho salmon in the ponds and main-stem.

Captured coho salmon were collected in five gallon buckets and anesthetized with clove oil prior to scale collection. The fish were measured in mm to fork length. Scales were collected from the first, second, and third rows of scales above the lateral line below the posterior end of the dorsal fin (Scarnecchia 1995). A minimum of ten scales were collected from each fish. After scale collection, fish recovered in aerated five gallon buckets and were redistributed throughout the pond in which they were caught.

The coho salmon scales were aged using a light microscope at 100x magnification to count the number of annuli present on each scale. Annuli were counted along a line 20 degrees ventral to the longest axis of the scale (Scarnecchia 1995). Multiple scales were examined prior to selecting a scale for aging each fish to ensure that regenerated scales with large or irregular centers were excluded from examination. The average lengths and standard deviations for each age class (age 0, age 1, and age 2 as determined from scales) were calculated.

In addition, age classes were identified using the Bhattacharaya method (Gayanilo et al. 2005) of modal progression analysis for the May through September catches. In this method, fish are divided into appropriate age classes from frequency-length distributions by connecting means and modes that appear to belong to the same age group. Software program FiSAT II (Rome, Italy) was used for the analysis. Frequency-length data from the ponds were pooled. For September data, age classes identified using modal progression analysis were compared with the scale age data to determine the validity of the modal progression analysis. A Z-test was used to compare the mean lengths for each age class from the scale data to the mean lengths from the modal progression analysis.

For May-September, the age class structure of coho salmon caught in the ponds was compared to the age structure of coho salmon caught in the main-stem Eklutna River. The total number of coho salmon in each age class and the proportion of each age class in the total catch were calculated for both habitat types (ponds/ main-stem).

Water Temperature and CPUE

Observations made during the May-July CPUE sampling events indicated that coho salmon distributions within the ponds may be affected by water temperature. To further investigate this observation, in August and September, water temperature was measured at each of the 32 trap locations throughout the three ponds, immediately after each minnow trap was set. Pearson's correlation coefficients were calculated to determine the relationship between trap CPUE and water temperature. August and September were analyzed separately to determine if the relationship between CPUE and temperature is different in a month (August) with warmer water temperatures relative to a month (September) with colder water temperatures. An additional Pearson's correlation coefficient was calculated to determine the relationship between total pond CPUE and the average water temperature in pond inlets and outlets from May-September. The analysis was conducted using the software program PASW 18 (IBM Corporation Somers, NY).

RESULTS

Relative Abundance/CPUE

Coho salmon were caught in the ponds and main-stem channel habitats every month from May-September 2010. From May-August, CPUE in Pond 1 was higher than in Ponds 2 and 3. CPUE was higher in Pond 1 than in the main-stem habitats in every month except June, when CPUE in the ponds substantially declined. From July-September, CPUE in Pond 1 declined while CPUE in Ponds 2 and 3 increased. In September, all three ponds had higher CPUEs than the main-stem habitat (Figure 7).

CPUE significantly differed across the four habitats in July and August. In July, Pond 1 had a significantly higher CPUE than Pond 2, Pond 3, and the main-stem ($H(3)= 29.27$, $p= 0.01$). In August, Pond 1 had a significantly higher CPUE than Pond 3 ($H(3)= 14.93$, $p= 0.01$). CPUE did not significantly differ across habitats in May ($H(3)= 5.84$, $p= 0.12$), June ($H(3)= 2.79$, $p= 0.42$), and September ($H(3)= 5.41$, $p= 0.14$).

Trends in coho salmon distribution were apparent. In May, coho salmon were numerous around the shorelines of all three ponds. In June, coho salmon were scarce near the shorelines. In July and August coho salmon were numerous in mid-pond habitats, with the highest catches in the middle and lower sections of Pond 1. In September, coho salmon were caught throughout all three ponds in both shoreline and mid-pond habitats. Catches were low in traps set in thick aquatic vegetation throughout the study.

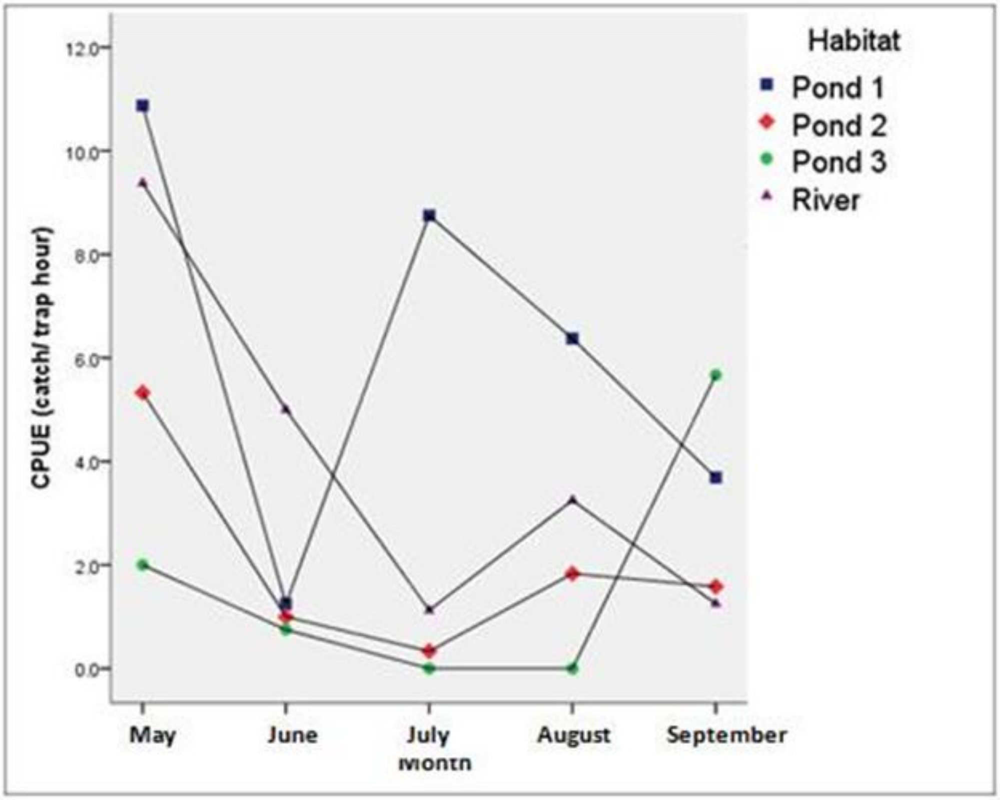

Figure 7: CPUE for the three ponds and one main-stem river habitat in the Eklutna River from May-September.

Water Quality

Water temperature in the off-channel ponds exceeded the state standards for anadromous fish rearing during this study (Table 7). Water temperatures in the ponds averaged between 12.9 and 14.6ºC over the entire study period. In July and August, water temperatures peaked in Ponds 2 and 3 (16.5 and 17.5ºC, respectively), and below the inlet channel in Pond 1 (16.1ºC). Average temperature in the main-stem was 7.3ºC, and it did not exceed 9.5ºC. DO levels in the ponds were within the accepted range (ADEC 2009), with the average DO in all three ponds around 13.6 mg/L. The pH level was within the ADEC (2009) guidelines as well, with an average pH of

7.2 in the ponds. Conductivity was high in Ponds 2 and 3, averaging 458 µS. Temperature, DO, pH, and conductivity in the main-stem were within the recommended limits.

Table 7: Water quality results for the three pond inlets and outlets and the main-stem habitat of the Eklutna River over the entire study period. The average (Avg.) and range for each water quality parameter are reported by habitat. The individual trap temperature measurements from August and September are not included.

Habitat	Temperature (°C)		Dissolved Oxygen (mg/L)		pH		Conductivity (µs)	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
Pond 1	12.9	9.4-16.1	13.9	12.0-15.0	7.1	7.0-7.4	391.5	332.6-474.4
Pond 2	14.4	11.9-16.5	13.9	11.1-15.8	7.2	7.0-7.4	447.3	328.3-549.3
Pond 3	14.6	11.6-17.5	12.9	10.3-16.2	7.3	7.1-7.5	468.4	361.5-543.2
Main-stem	7.3	4.6-9.5	13.6	12.5-15.1	7.4	7.3-7.5	381.6	360.2-406.3

Physical Habitat

Pond 1 was the largest and deepest pond (Appendix B.16). It was deeper (1.4 m) in the middle and in the lower section, and shallower around the shorelines (<0.6 m). Pond 2 was slightly smaller than Pond 1, with shallower depths (<1 m) throughout the pond (Appendix B.17). Pond 3 was the smallest (Appendix B.18), and it was connected to a small channel of surface water leading to a nearby wetland (Appendix B.19). The three ponds were connected via large channels ranging from 5-11 m wide (Appendix B.20). The channels were 0.6-0.8 m deep. Pond 1 was connected to the Eklutna River by two channels each 7-9 m wide and 0.9-1.2 m deep (Appendix B.21). The outflow channel on the southern side of Pond 1 was blocked by a beaver dam, but the second connective channel was free of blockages. The channels were divided by a small sand bar in the middle. Salmonids were observed moving through the channels connecting Pond 1 to the Eklutna River in all months. During high tide, fresh river water backed up into Pond 1 increasing water depths and pond surface areas. Water levels in the ponds increased during the highest high tides. Water in the ponds was clear to the substrate in July and September. However, in May, June, and August the water was turbid, especially in the deeper sections of Pond 1. Pond substrate consisted of silt and mud.

Pond shoreline vegetation consisted of tall grasses, sedges, and alders. There was little canopy cover around the shorelines, and the ponds were exposed to direct sunlight. The shallower parts of Pond 1 around the shorelines, and all of Ponds 2 and 3 were filled with pond weed (*Potamogeton spp.*) from June through August. No aquatic vegetation was present in May, and it had died off prior to the September sampling. Large numbers of sticklebacks were caught in traps submerged in aquatic vegetation in May, June, and July. There was no large woody debris in the ponds.

Population Structure Analysis

Population Estimate/ Mark-recapture

A total of 179 coho salmon were tagged in the initial marking event, and 348 coho salmon were caught during recapture, 17 of which were marked. The population estimate for coho salmon larger than 60 mm fork length in Pond 1 was 3,490 (95% CL 2,228-5,763, S.E. ± 780), with a density of 57 coho salmon/ 100 m^2. None of the tagged coho salmon were caught in the main-stem during the August and September CPUE samplings. However, two tagged fish were caught in Pond 1 during the August CPUE sampling, and three were caught in Pond 3 during the September CPUE sampling.

Coho Age Structure

Scales were collected from 98 coho salmon ranging in size from 44-115 mm. The mean lengths from the scale data did not significantly differ from the mean lengths from the modal progression analysis (age 0, $Z= 0.40$, $p= 0.68$; age 1, $Z= -1.96$, $p= 0.14$; age 2, $Z= 0.64$, $p= 0.74$; Table 8), indicating that the age classes generated using the modal progression analysis were comparable to age classes obtained from scales and the analysis could be extended to May-August data.

The age structure of coho salmon differed seasonally between the ponds and main-stem habitats (Figure 8). In May and June, age 1 and 2 coho salmon were predominate in both pond and main-stem habitats (Figure 9). In July, age 2 coho salmon predominated in the ponds and main-stem. In August and September, coho salmon in the ponds were mostly age 1 and 2 while coho salmon in the main-stem were all age 0 and age 0 and 1. Coho salmon size at age for fish aged using scales ranged from: Age 0, 44-63 mm; Age 1, 63-89 mm, and Age 2, 82-115 mm (Table 8).

Table 8: The average fork length (mm) and standard deviation of age 0, age 1, and age 2 coho salmon in the pond and main-stem Eklutna River habitats from May-September. Average lengths and standard deviations were determined using Bhattacharya's modal progression analysis. The grey areas represent the age classes in which no coho salmon were caught.

	Age 0	**Age 1**	**Age 2**
May Ponds		61.9 ± 8.22	91.5 ± 6.73
May Main-stem		63.4 ± 8.28	104.5 ± 11.17
June Ponds		67.5 ± 6.01	87.7 ± 7.75
June Main-stem		75.9 ± 5.96	
July Ponds	53.2 ± 4.42	71.1 ± 5.30	92.5 ± 7.08
July Main-stem			100.0 ± 9.50
August Ponds	60.9 ± 2.99	80.0 ± 7.76	99.3 ±7.08
August Main-stem	55.2 ± 6.23		
September Ponds	50.0 ± 5.14	73.6 ± 7.52	100.3 ± 5.55
September Main-stem	55.0 ± 4.25	58.8 ± 6.69	

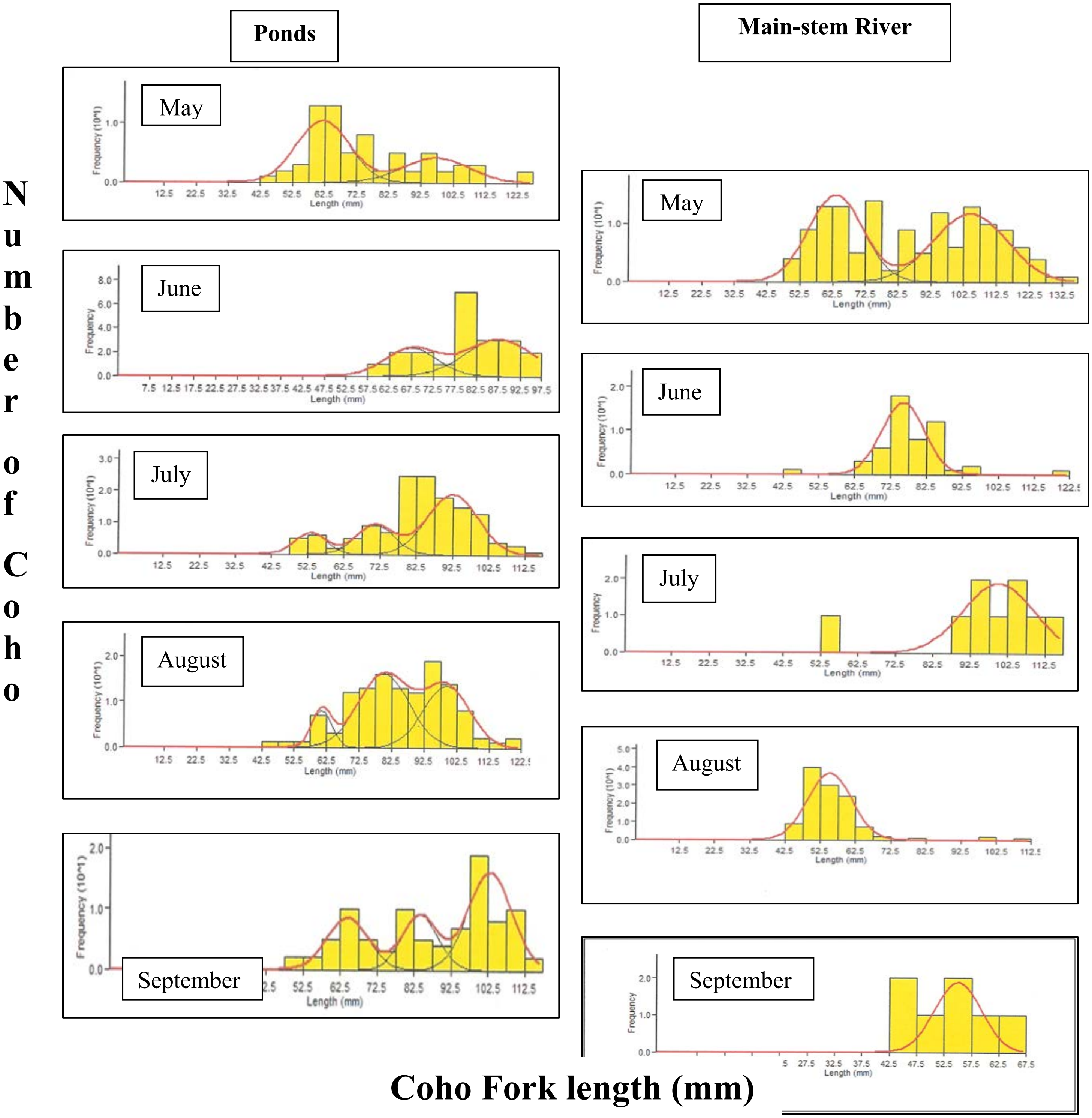

Figure 8: Length-frequency histograms for the ponds and main-stem river habitat in the Eklutna River from May-September. Length distributions for age classes (line) were created using Bhattacharaya's method of modal progression analysis.

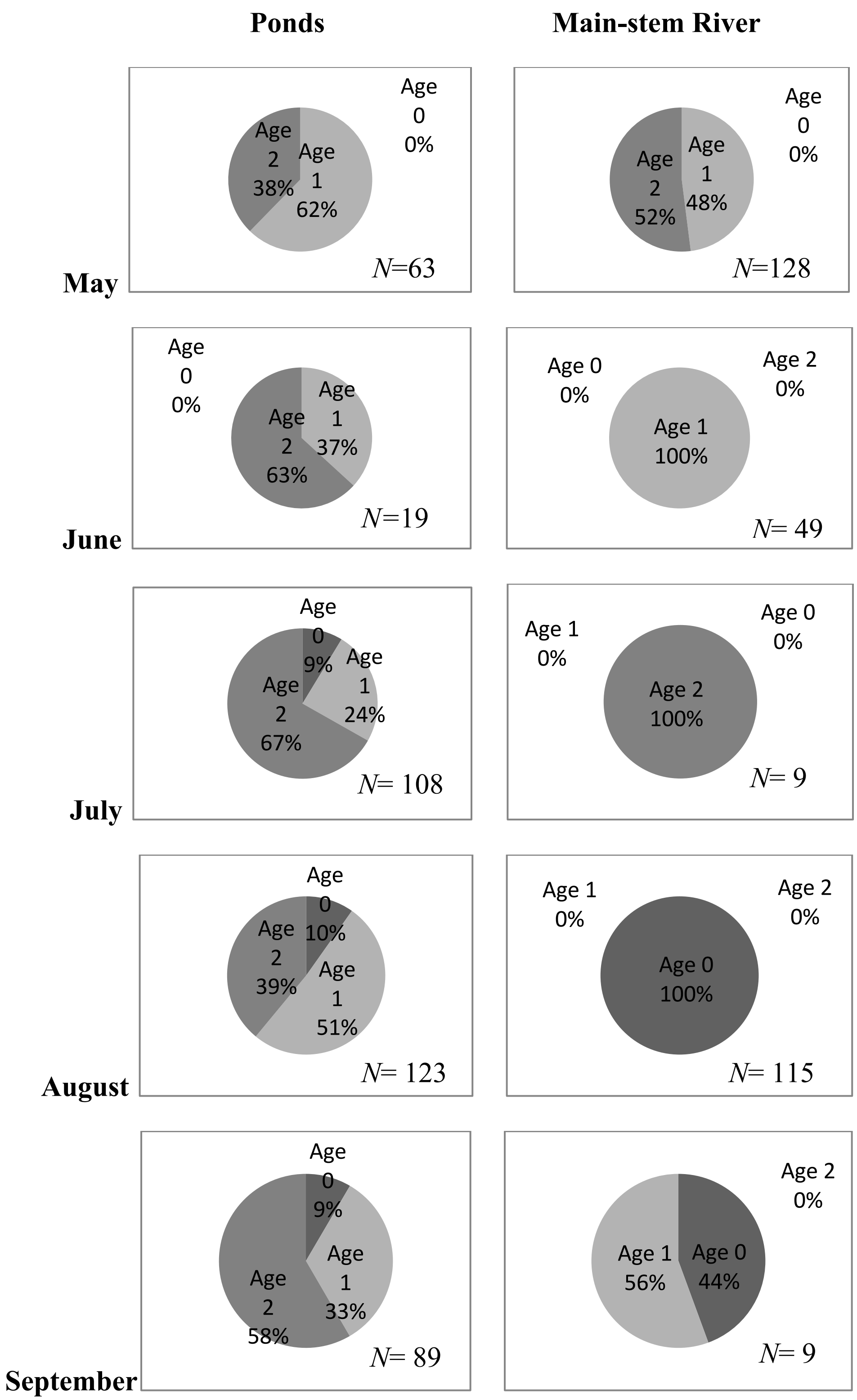

Figure 9: The proportion of age 0, age 1, and age 2 coho salmon caught in Eklutna River ponds and main-stem habitats from May-September.

Water Temperature and CPUE

There was no correlation between average pond and river CPUE and average water temperature in the pond inlets and outlets and main-stem river from May-September (R= -0.193, p= 0.42; Figure 10). There was a negative correlation between trap CPUE and trap water temperature in the ponds (r= -0.741, p= 0.01) in August (Figure 11), and no relationship in September (r= 0.46, p= 0.80; Figure 12). CPUE was higher near optimum temperatures (11.8-14.6°C) and lower at temperatures below and above optimum.

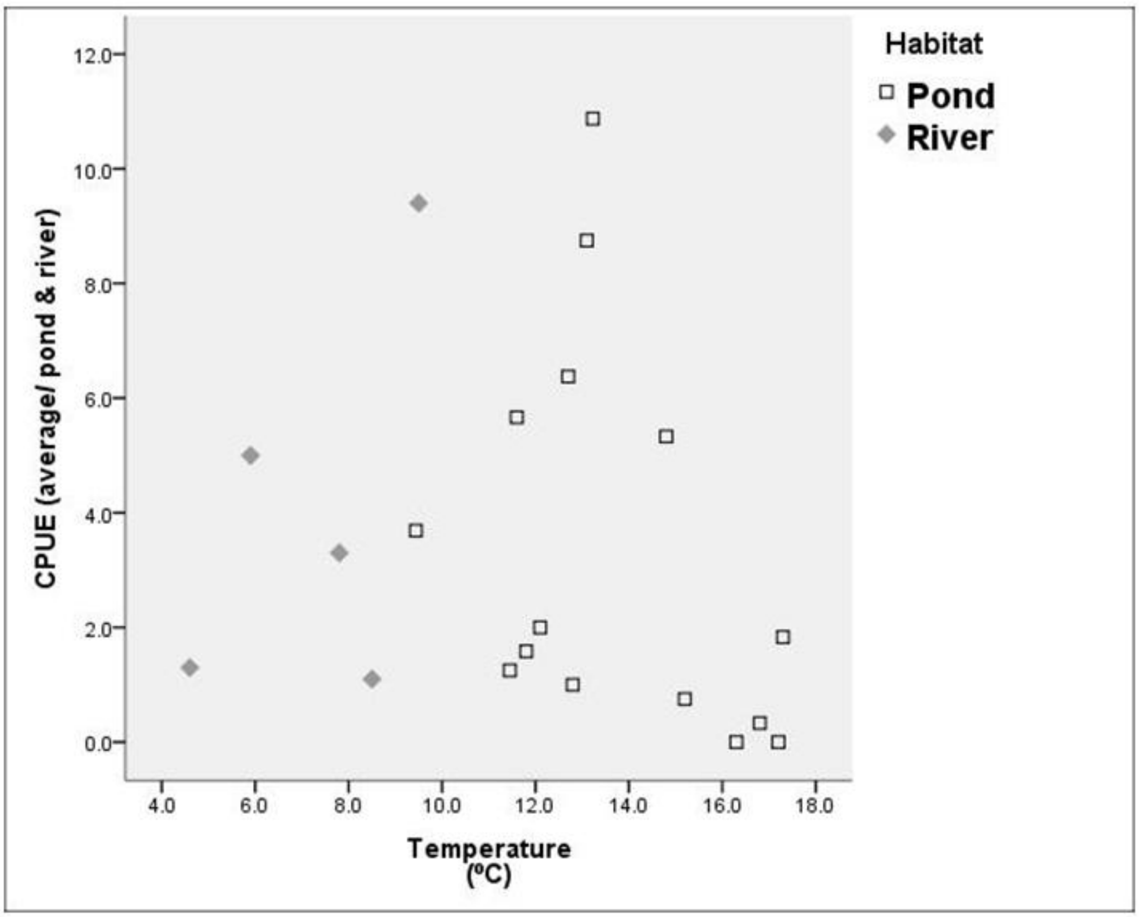

Figure 10: CPUE is higher near optimum temperature (11.8-14.6°C) and lower at temperatures below and above optimum in the Eklutna ponds and main-stem river from May-September.

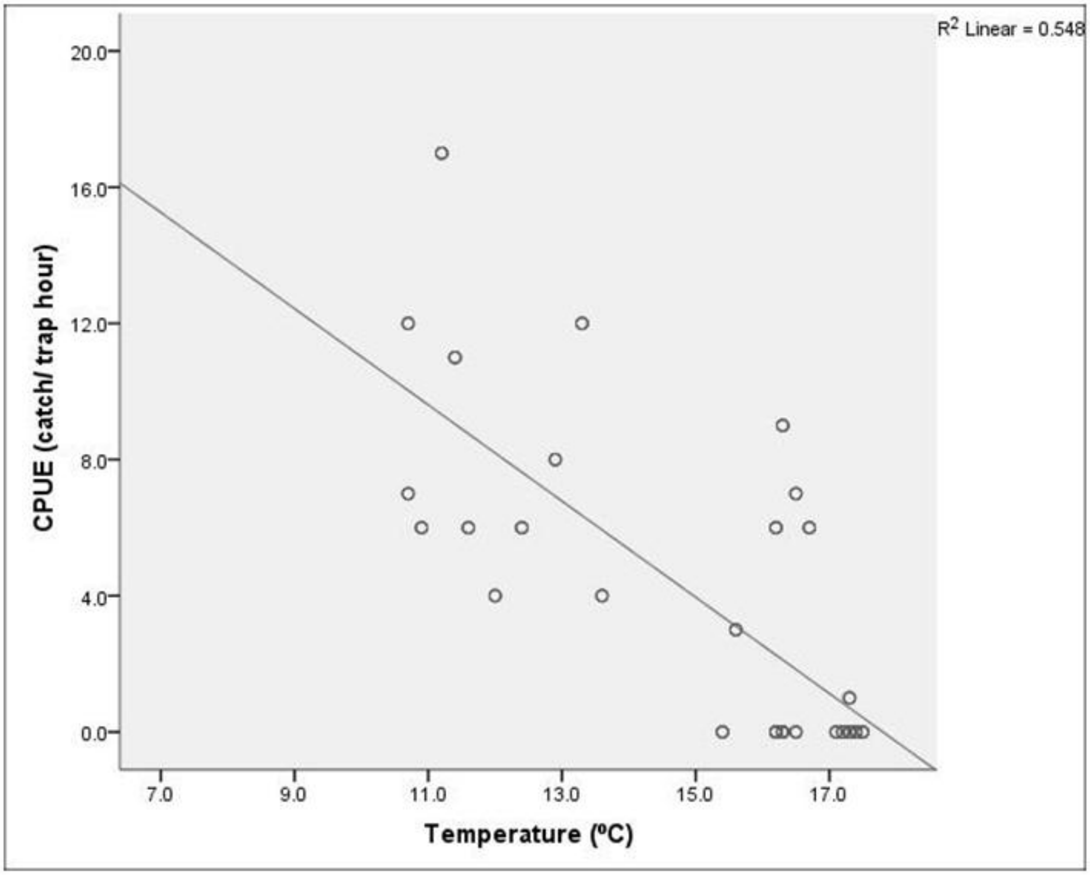

Figure 11: Negative correlation between trap CPUE and trap water temperature in the Eklutna Ponds in August. Temperatures reached 17.5ºC.

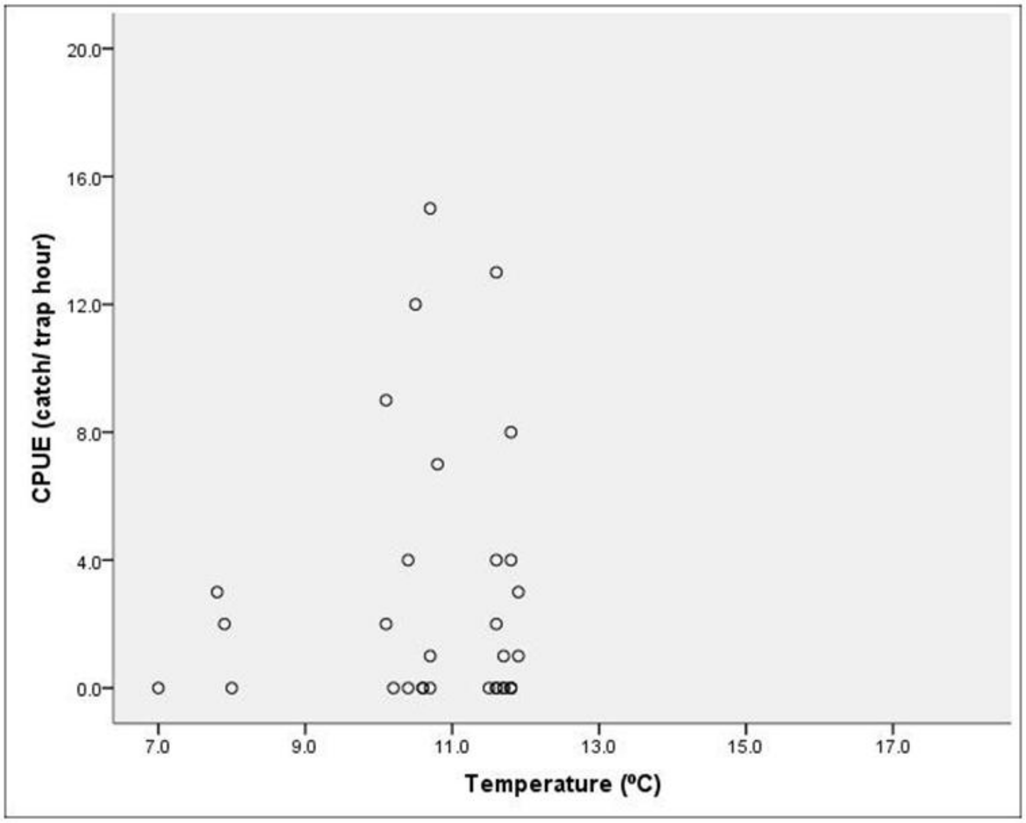

Figure 12: No correlation between trap CPUE and trap water temperature in the Eklutna Ponds in September. Temperatures did not exceed 12.1ºC. The potential for high CPUE is present at the high end of the temperature range, where temperatures approach the coho salmon optimum.

DISCUSSION

Several trends in relative abundance were observed between pond and main-stem habitats. The high relative abundances of fish larger than 85 mm in the main-stem channel in May coincided with smolt outmigration (Drucker 1972). The Eklutna ponds and main-stem channel adjacent to the ponds are located in the upper zone of tidal influence, in a freshwater marsh habitat. Similar marsh habitats are used by outmigrating coho salmon smolts to begin the smoltification process, and coho salmon grow rapidly in these habitats prior to entering the ocean, improving their chances of ocean survival (Miller and Sadro 2003). Relative abundance may be highest in May because outmigrating coho salmon are using the lower main-stem Eklutna River and ponds to smolt. Age 0 catches were very low in both habitats in May and June because the 1/4” trap mesh size is biased against smaller young-of-year individuals. Age 1 and age 2 coho salmon were common in the ponds from May- September; thus, more older individuals utilize the pond habitat for summer rearing while age 0 individuals predominately utilize the main-stem.

Relative abundance varied seasonally in the pond and main-stem habitats. The sharp decline in relative abundance in the ponds in June is due to sampling design error. The fish moved out of shoreline habitats and no traps were set in mid-pond habitats; thus, relative abundance did not represent the true population in the ponds in June. The high relative abundance in all three ponds in September coincided with the typical fall coho salmon migration into off-channel habitats to overwinter (Bramblett et al. 2002). Coho salmon may utilize the deeper pond habitats to overwinter. However, winter coho salmon sampling would be necessary to confirm that fish are utilizing the habitat.

Several factors likely contributed to the changes in coho salmon distribution in the ponds. A thick overgrowth of aquatic vegetation in Ponds 2 and 3, and higher water temperatures may have contributed to the movement of coho salmon from Ponds 2 and 3 to Pond 1 from June to August. In September when the aquatic vegetation was gone and water temperatures were lower, coho salmon were distributed more evenly around the shorelines and middle of all three ponds. From June through August when aquatic vegetation was abundant and water temperatures were warmer, coho salmon were distributed predominately in the middle and lower section of Pond 1. The presence of tagged Pond 1 coho salmon in Pond 3 during the September CPUE sampling shows that fish moved throughout the pond system later in the season, when temperatures decreased and aquatic vegetation died. Tagged coho salmon were only caught in Pond 1 during August, and no tagged fish were caught in the main-stem. Thus, coho movement throughout the pond system and between pond and adjacent main-stem habitats may have been minimal from July to August.

Water temperature influences coho salmon populations in the Eklutna ponds. Water temperature in the lower section and middle of Pond 1 was buffered by high tides, which pushes cold river water into the pond keeping temperatures cooler than Ponds 2 and 3. In August and September, coho salmon catches in the ponds were higher at trap locations close to optimum temperature (11.8-14.6°C). Warm and cold water temperatures affect the metabolism, growth, migration, behavior, and survival of coho salmon (Lee et al. 2003), and they influence habitat selection and fish distribution (Selong et al. 2001). Optimal temperatures for coho salmon metabolism and growth are between 11.8 and 14.6ºC (Reiser and Bjornn 1979). Thus, coho salmon appeared to move into Pond 1 where temperatures are in the optimum range for growing and metabolizing earlier in the season (Reiser and Bjornn 1979), and are more widely distributed throughout all three ponds when temperatures are cooler in September.

The Eklutna River is glacial stream system with water temperatures below the optimum for coho salmon growth and metabolism. Additionally, off-channel ponds are not naturally present on the Eklutna River, which mostly flows though a steep canyon with little to no quality coho salmon habitat. Thus, the Eklutna pond habitat restoration project creates a highly productive thermal niche that is not naturally present in the stream system. Although it is difficult to assess how the Eklutna ponds contribute to coho salmon production in the Eklutna River, the ponds may be very important because quality in-stream coho salmon habitat is lacking. Artificial off-channel ponds may contribute to coho salmon production more on glacial streams with limited in-stream habitat and cold water temperatures.

Coho salmon habitat in the Eklutna ponds could be improved by reducing water temperatures below 15ºC throughout the pond system. Deepening the ponds and planting tall riparian vegetation along the shoreline to provide shade would help reduce water temperatures. Connecting off-channel ponds directly to surface water flow from the main-stem channel is another viable option for reducing water temperatures on non-glacial stream systems. However, directing surface water flow through artificial pond habitats on glacial systems, such as the Eklutna River, is problematic because large quantities of silt and sediments would be deposited in the ponds, reducing pond depth and available habitat. The ponds would need to be dredged regularly to maintain depth.

The thick overgrowth of aquatic vegetation in the Eklutna ponds can raise water temperature and it can reduce the amount of DO in the water, especially during the fall and winter when the plants die and decay (Kramer 1987). In addition to influencing water temperatures, the vegetation affects the amount of coho salmon habitat available in the ponds. The low coho salmon catches in traps set in aquatic vegetation, and observations of very few fish in Ponds 2 and 3 in months when aquatic vegetation was abundant, indicate that coho salmon do not prefer habitats with thick aquatic vegetation. Additionally, the vegetation supported large populations of sticklebacks (*Gasterosteus aculeatus*) from May-July, with stickleback CPUE seven times higher than coho salmon CPUE. Sticklebacks utilize ponds to spawn and rear, and they prefer habitats with aquatic vegetation (Bryant 1988). The large number of sticklebacks in the Eklutna ponds increases competition for food and quality rearing habitats (Bryant 1988). Increasing water depth in the ponds so the substrate is below the light penetration zone would help control aquatic vegetation, and increase the amount of coho salmon habitat available. Adding large woody debris to the ponds would provide cover and increase habitat complexity as well (Lister and Genoe 1970).

The Eklutna off-channel ponds have wide, deep, low velocity access channels connecting the three ponds to one another and Pond 1 to the main-stem. The access channels are connected to the main-stem year-round, making the pond habitats accessible to coho salmon. Having two connective channels kept the habitat accessible despite the beaver dam impairing fish passage in one channel. Additionally, the beaver dam is swept away during the highest tides, naturally clearing the access channels to the ponds. Since juvenile salmonids were observed moving through the channels connecting Pond 1 to the main-stem in all five months, it appears that maintaining year-round pond-main-stem connectivity contributes to the success of this pond habitat restoration, and that it is an important feature of all artificially built off-channel habitats.

The analysis of the population estimate data showed that the lower Eklutna pond (Pond 1) supports a large summer coho salmon population (3,490 coho >60 mm). The actual coho salmon population in this pond is likely larger than the population estimate calculated in this study because fish under 60 mm in fork length were excluded from tagging. A comparable (7,644 m^2) gravel pit pond in southeast Alaska supported smaller coho salmon populations (2,500) in August than the Eklutna River pond (Bryant 1984). Larger ponds in southeast Alaska ranging from 10,010 m^2 to 34,954 m^2 only supported 3,500 coho salmon per pond (Bryant 1984). Coho salmon densities in natural off-channel habitats in southeast Alaska ranged from 9-59 coho/ 100 m^2 (Elliott and Hubartt 1983). Thus, coho salmon densities in Pond 1 were higher than gravel pit ponds, and they were comparable to natural off-channel habitats in southeast Alaska, indicating that Pond 1 is a highly productive summer habitat that functions similarly to natural off-channel habitats.

Several factors contribute to the high coho salmon productivity in Pond 1, and may make Pond 1 a better coho salmon habitat than Ponds 2 and 3 for most of the year. The middle and lower sections of Pond 1 do not have aquatic vegetation while Ponds 2 and 3 have thick vegetation growing to the water's surface. Water temperature in Pond 1 is within the optimum temperature range for growth and metabolism while temperatures in Ponds 2 and 3 exceed the optimum 11.8-14.6ºC (Reiser and Bjornn 1979) for much of the summer. The water is deeper in Pond 1, helping to reduce water temperatures and provide cover from predators. The high tides may enhance Pond 1 habitat by bringing nutrients and food, such as macroinvertebrates, from the main-stem channel. I believe that these factors make Pond 1 a better rearing habitat for coho salmon than Ponds 2 and 3.

The age structure of juvenile coho salmon in the Eklutna ponds was comparable to the age structure of coho salmon in natural beaver ponds in southeast Alaska as well. Coho salmon in beaver ponds were older (89% age 1) than coho salmon in main-stem habitats (96% age 0; Murphy et al. 1989). Off-channel pond habitats may be preferable to main-stem habitats in the Eklutna River because water temperatures in the ponds are warmer, with average temperatures near the optimum range for coho salmon growth (Reiser and Bjornn 1979). The average water temperature in the main-stem was well below the optimal rearing temperature range. Due to warmer temperatures and lower energy demands, coho salmon reared in ponds typically grow faster, are larger, and have increased survival rates (Swales and Levings 1989; Rosenfield 2008). Comparisons of juvenile salmon production in natural, off-channel and main-stem habitats indicate that off-channel habitats can be more productive than main-stem habitats (Leidholt-

Brunner et al. 1992). Thus, the off-channel pond habitats may be preferred over main-stem habitats, and the older fish (age 1 and age 2) present in high densities in the Eklutna ponds can likely outcompete small age 0 fish for the better quality pond territories (Mundie 1969; Sandercock 1991).

The abundance of age 2 coho salmon in the ponds may be due to the slow growth experienced in the Eklutna stream system. Age 1 coho salmon were smaller (65-85 mm) than the 100 mm size at which coho salmon typically migrate (Gribanov 1948). Coho salmon in colder stream systems will stay in freshwater longer to compensate for slower growth and to increase their ocean survival chances (Gribanov 1948). The cold temperatures and slow growth apparent in the Eklutna River likely contribute to the abundance of age 2 fish present in the ponds.

Adult spawning in the Eklutna River occurs higher in river system, with spawning surveys indicating that most of the spawning occurs above the Old Glenn Highway Bridge (Hoffman pers. comm.). After emerging from the gravel, fry typically stay within a few meters of the redd (Kahler and Quinn 1998). During the summer, fry move a few hundred meters on average with movement predominately upstream (Kahler and Quinn 1998). In fall, fry may move several kilometers, with movements mostly upstream into off-channel habitats (Peterson and Reid 1984). Because spawning occurs higher in the Eklutna River (Hoffman pers. comm.) and juvenile salmonid movement is usually upstream (Kahler and Quinn 1998), age 0 recruitment to the lower river reaches and Eklutna ponds may be limited.

CONCLUSION

The success of the Eklutna River artificial off-channel habitat restoration yields important information about the types of restored habitats that are utilized by coho salmon. Future restorations could use the Eklutna ponds as a model for designing effective fish habitats, and they should implement the following structural designs to maximize fish utilization of the habitats: 1) construct several smaller ponds around 6,000 m^2 instead of large ponds (>7,000 m^2) to maximize coho salmon productivity; 2) create multiple access channels that are wide (9 m) and deep (>1m), to improve year round fish access to off-channel habitats; and 3) increase mid-pond depths to 1.5-2 m to decrease water temperatures and limit aquatic vegetation growth. I believe that including these features in off-channel habitat designs has the potential to increase coho salmon use of artificial off-channel habitat.

Chapter 4: Conclusion

The Resurrection Creek off-channel habitat restoration was utilized by coho salmon during part of this study, and the Quartz Creek Pond and North Fork Little Campbell Creek alcove were not utilized. The Eklutna River ponds were used by coho salmon throughout the entire study period, with the lower Eklutna Pond (Pond 1) supporting a large summer coho salmon population. Many morphological habitat features contributed to whether the restorations evaluated in this study functioned as coho salmon habitats.

Habitat Morphology

One of the most important morphological features that partly determines the success of fish habitat restorations is the location of the restoration project. The problems encountered at Quartz Creek Pond highlight the importance of carefully selecting the location of off-channel habitat restorations. The Quartz Creek restoration project constructed an artificial habitat in a location where the artificial habitat was not compatible with the natural conditions and ecology of the site (Roni et al. 2002). Since the restoration was built in an area that is naturally forested with no surface water, the habitat relies on a groundwater fed stream channel to provide adequate connectivity. This can lead to problems because a single blockage or change in the groundwater aquifer level can eliminate fish access to the entire off-channel habitat and render that habitat useless for juvenile salmonids. Since the habitat is far away from the stable flow of Quartz Creek and the natural floodplain, there are very few options to improve pond connectivity to the main-stem channel and keep this habitat accessible for salmonids.

Habitat restorations are often constructed in locations that are not compatible with natural background conditions because it is cheaper and more convenient (Roni et. al 2002). To avoid some of the connectivity and fish access problems associated with poorly selected restoration locations, the focus of future habitat restorations should be on restoring the river processes that create natural off-channel habitats on the floodplain (Roni et. al 2002). Restoring natural river processes in rivers with altered flow regimes and channelization allows the river to continually create new natural off-channel habitats on its own.

The Resurrection Creek study site was the only habitat restoration evaluated in this study that restored river processes in addition to creating artificial off-channel ponds for rearing juvenile salmonids. Although river processes were restored, natural shifts in the channel and flow regime reduced main-stem- off-channel pond connectivity, impairing year-round access to the habitat. Opportunities to restore river processes on the Eklutna River and LCC are very limited because water withdrawals from the Eklutna River permanently alter the flow regime, and urbanization surrounding LCC prevents the restoration of its confined channels. The Quartz Creek pond is too far away from Quartz Creek to be influenced by river process restoration. However, restoring river processes on sections of Quartz Creek impaired by mining and construction could lead to the creation of new off-channel habitats that are similar to the natural conditions in Quartz Creek.

Another important morphological feature that influences coho salmon utilization of off-channel habitats is the size and type of habitat constructed. Coho salmon typically utilize off-channel ponds that are similar to natural beaver ponds (Leidholt-Brunner et al. 1992) and they prefer shallower shoreline habitats (Swales and Levings 1989). Restriction in the size of off-channel ponds is important because smaller ponds tend to be more productive (Roni et al. 2002). Lister and Finnigan (1997) recommend that pond sizes do not exceed 3,000 m^2, although the 6,000 m^2 Eklutna pond evaluated in this study was a very productive habitat. Several smaller ponds ($\leq$6,000 m^2) are more productive than larger ponds (>10,000 m^2; Bryant 1984). Thus, I believe that the ideal off-channel coho salmon habitat would consist of multiple ponds smaller than 6,000 m^2, with shallow depths ranging from one to two meters.

Physical Habitat Characteristics

There are several important physical habitat characteristics that contribute to off-channel habitat use by fishes. The habitats that were not functioning during this study shared some common characteristics that contributed to the lack of fish in the habitats including: a lack of clearly defined access channels that were free of blockages and that maintained year-round connectivity to the main-stem channel; minimal amounts of riparian vegetation and limited canopy cover; insufficient water depths; and water quality impairments.

Pond- main-stem connectivity and access channels that allow fish passage are two of the most important physical characteristics that influence coho salmon off-channel habitat utilization (Bryant 1984). Year-round access to off-channel habitats is necessary to ensure that fish can freely move in and out of the off-channel habitats on a seasonal basis. Off-channel habitat access can be improved by constructing inlet channels with perennial surface water flow and outflow channels that maintain connectivity with the main-stem. The inlet and outlet channels in each pond should be connected directly to the main-stem to help ensure year-round connectivity. Inlet channels should flow from outer river bends to minimize sedimentation in the ponds (Lister and Finnigan 1997). Constructing a series of ponds that are connected together should be avoided because a change in inlet water flow or a blockage in the outlet or inlet channel could restrict fish access to the entire pond system. Access channels that are wide (7-9 m), deep (>1 m), and that have low velocity water flow, similar to the Eklutna River pond- main-stem access channels, appear to enable sufficient fish passage.

Another physical habitat characteristic that is important to the function of off-channel habitats is the type and amount of riparian vegetation along the shoreline. Increasing the amount of tall woody riparian vegetation surrounding off-channel habitats increases canopy cover and provides shade to the off-channel ponds, which are lentic and prone to warm summer temperatures (Roni et al. 2002). Riparian vegetation is a critical feature in lentic habitats because it provides shade, reducing water temperatures (Roni et al. 2002). Large woody debris is an important component in off-channel ponds as well. Large woody debris should be numerous in off-channel ponds to provide cover and add habitat complexity (Lister and Finnigan 1997).

Water Quality

Water quality in off-channel habitat restorations is also important. High water temperatures and low DO levels can render a restored habitat unusable for coho salmon. Habitats with extremely shallow depths, such as the Little Campbell Creek alcove, tend to have high mid-summer water temperatures that exceed the tolerance of juvenile coho salmon. Additionally, habitats that are solely groundwater fed, such as LCC alcove and Quartz Creek Pond, tend to have low DO levels, especially during winter months. To improve water quality in off-channel ponds, it is necessary to connect the ponds to a surface water input from the main-stem channel and increase mid-pond water depth. Deeper pond habitats (>2 m) have cooler water temperatures (Bryant 1984), but coho salmon prefer shallow water habitats around 1-1.5 m (Swales and Levings 1989). I believe that pond depths should be between 1-1.5 m around the shoreline with depths increasing to two meters in mid-pond habitats to help buffer water temperatures.

Project Monitoring

Current and future habitat restorations could be improved by post-project monitoring. Monitoring projects after completion helps us understand how and when target fish species utilize artificial habitats (Roni et al. 2002). Habitat restorations should be evaluated every two years to ensure that the habitats are still functioning as fish habitats and that the access channels are free of blockages. If the habitats are not functioning due to blockages or poor water quality, project managers could work on reopening them for fish use. It is nearly impossible to anticipate all the natural changes that could impair the function of artificial habitats after the restoration is complete. Thus, it is important to obtain grant money or set aside project money to monitor habitats after construction and to fix habitats that are not functioning.

Building artificial off-channel habitats has the potential to increase juvenile coho salmon production, especially on heavily modified stream systems that are lacking natural off-channel floodplain habitats (Roni et. al 2002). Off-channel floodplain habitats, such as ponds, sloughs, and side-channels, can produce more and larger smolts with higher survival rates than other habitat types (Roni et al. 2002). Habitat restoration project managers should focus on restoring the natural river processes that create off-channel pond habitats (Roni et al. 2002). If river processes cannot be restored, constructing small ponds in old floodplain channels that can be connected to year-round surface water flow (Lister and Finnigan 1997) is a viable option to create new coho salmon rearing habitats on impaired stream systems.

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Appendix A: Examples of Physical Habitat Assessment Sheets

PHYSICAL CHARACTERIZATION/WATER QUALITY FIELD DATA SHEET (FRONT)

STREAM NAME	LOCATION	
STATION #________ RIVERMILE________	STREAM CLASS	
LAT _____________ LONG _____________	RIVER BASIN	
STORET #	AGENCY	
INVESTIGATORS		
FORM COMPLETED BY	DATE _______ TIME _______ AM PM	REASON FOR SURVEY

WEATHER CONDITIONS	**Now** / **Past 24 hours** ☐ storm (heavy rain) ☐ ☐ rain (steady rain) ☐ ☐ showers (intermtt) ☐ ____%☐ %cloud cover ____% ☐ ☐ clear/sunny ☐ Has there been a heavy rain in the last 7 days? ☐ Yes ☐ No Air Temperature_____ ° C Other________________________________
SITE LOCATION/MAP	Draw a map of the site and indicate the areas sampled (or attach a photograph)
STREAM CHARACTERIZATION	**Stream Subsystem** ☐ Perennial ☐ Intermittent ☐ Tidal **Stream Type** ☐ Coldwater ‘☐ Warmwater **Stream Origin** ☐ Glacial ☐ Spring-fed ☐ Non-glacial montane ☐ Mixture of origins ☐ Swamp and bog ☐ Other__________ **Catchment Area**_________km2

PHYSICAL CHARACTERIZATION/WATER QUALITY FIELD DATA SHEET
(BACK)

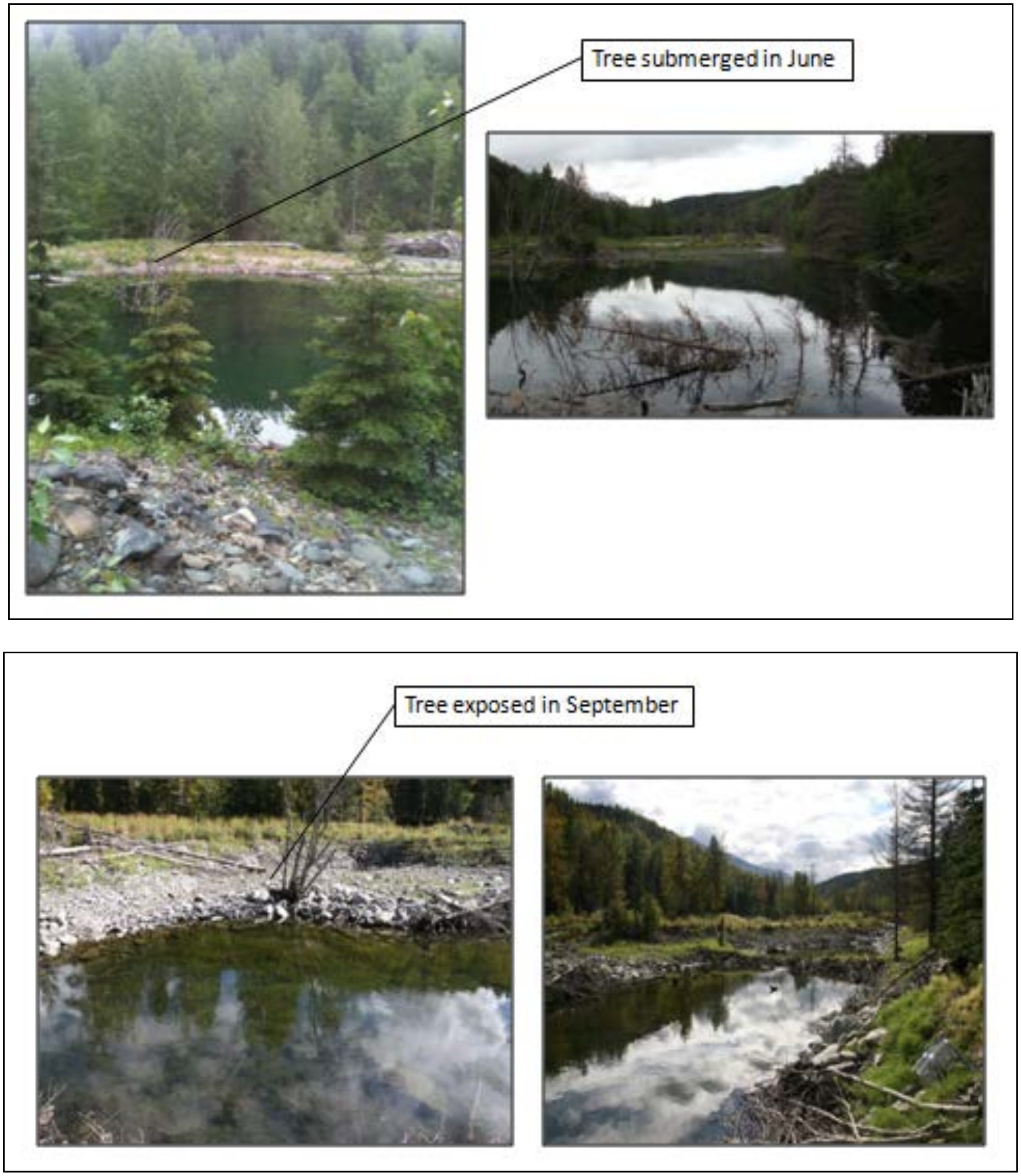
WATERSHED FEATURES	**Predominant Surrounding Landuse** ☐ Forest ☐ Commercial ☐ Field/Pasture ☐ Industrial ☐ Agricultural ☐ Other ☐ Residential ________	**Local Watershed NPS Pollution** ☐ No evidence ☐ Some potential sources ☐ Obvious sources **Local Watershed Erosion** ☐ None ☐ Moderate ☐ Heavy
RIPARIAN VEGETATION (18 meter buffer)	**Indicate the dominant type and record the dominant species present** ☐ Trees ☐ Shrubs ☐ Grasses ☐ Herbaceous dominant species present ________	
INSTREAM FEATURES	**Estimated Reach Length** _______m **Estimated Stream Width** _______m **Sampling Reach Area** _______m^2 **Area in km²** (m^2 x1000) _______km^2 **Estimated Stream Depth** _______m **Surface Velocity** _______m/sec (at thalweg)	**Canopy Cover** ☐ Partly open ☐ Partly shaded ☐ Shaded **High Water Mark** _______m **Proportion of Reach Represented by Stream Morphology Types** ☐ Riffle_______% ☐ Run_______% ☐ Pool_______% **Channelized** ☐ Yes ☐ No **Dam Present** ☐Yes ☐ No
LARGE WOODY DEBRIS	**LWD** _______m^2 **Density of LWD** _______m^2/km^2 (LWD/ reach area)	
AQUATIC VEGETATION	**Indicate the dominant type and record the dominant species present** ☐ Rooted emergent ☐ Rooted submergent ☐ Rooted floating ☐ Free floating ☐ Floating Algae ☐ Attached Algae **Dominant species present** ________ **Portion of the reach with aquatic vegetation** _____%	
WATER QUALITY	Temperature________ ° C Specific Conductance________ Dissolved Oxygen ________ pH ________ Turbidity ________ WQ Instrument Used ______________	**Water Odors** ☐ Normal/None ☐ Sewage ☐ Petroleum ☐ Chemical ☐ Fishy ☐ Other______________ **Water Surface Oils** ☐ Slick ☐ Sheen ☐ Globs ☐ Flecks ☐ None ☐ Other________________ **Turbidity** (if not measured) ☐ Clear ☐ Slightly turbid ☐ Turbid ☐ Opaque ☐ Stained ☐ Other
SEDIMENT/SUBSTRATE	**Odors** ☐ Normal ☐ Sewage ☐ Petroleum ☐ Chemical ☐ Anaerobic ☐ None ☐ Other______________________ **Oils** ☐ Absent ☐ Slight ☐ Moderate ☐ Profuse	**Deposits** ☐ Sludge ☐ Sawdust ☐ Paper fiber ☐ Sand ☐ Relict shells ☐ Other______________ **Looking at stones which are not deeply embedded,are the undersides black in color?** ☐ Yes ☐ No

INORGANIC SUBSTRATE COMPONENTS (should add up to 100%)			ORGANIC SUBSTRATE COMPONENTS (does not necessarily add up to 100%)		
Substrate Type	**Diameter**	**% Composition I n Sampling Reach**	**Substrate Type**	**Characteristic**	**% Composition inSampling Area**
Bedrock			Detritus	sticks, wood, coarse plant materials (CPOM)	
Boulder	>256 mm (10")				
Cobble	64-256 mm (2.5"-10")		Muck-Mud	black, very fine organic (FPOM)	
Gravel	2-64 mm (0.1"-2.5")				
Sand	0.06-2mm (gritty)		Marl	grey, shell fragments	
Silt	0.004-0.06mm				
Clay	<0.004mm (slick)				

Appendix B: Study Site Photographs

Resurrection Creek Pictures

B.1: Pond 1 during higher flow in June and July (top) and low flow in September (bottom). Substantial water level changes were apparent.



B.2: Pond 2 during high flow in June and July (top) and low flow during September (bottom). Substantial water level changes were apparent.

B.3: Pond 3 during high flow in June (top) and low flow in September (bottom). Substantial water level changes were apparent. An outflow channel was present in June and completely gone in September.

B.4: Pond 4 in June (top) and September (bottom). No surface inflow or outflow was apparent, and the water was turbid in June. Aquatic vegetation was abundant.

B.5: Side-channel flowing from Pond 3 to Pond 2, during high water flow in June (left) and low flow in September (right).

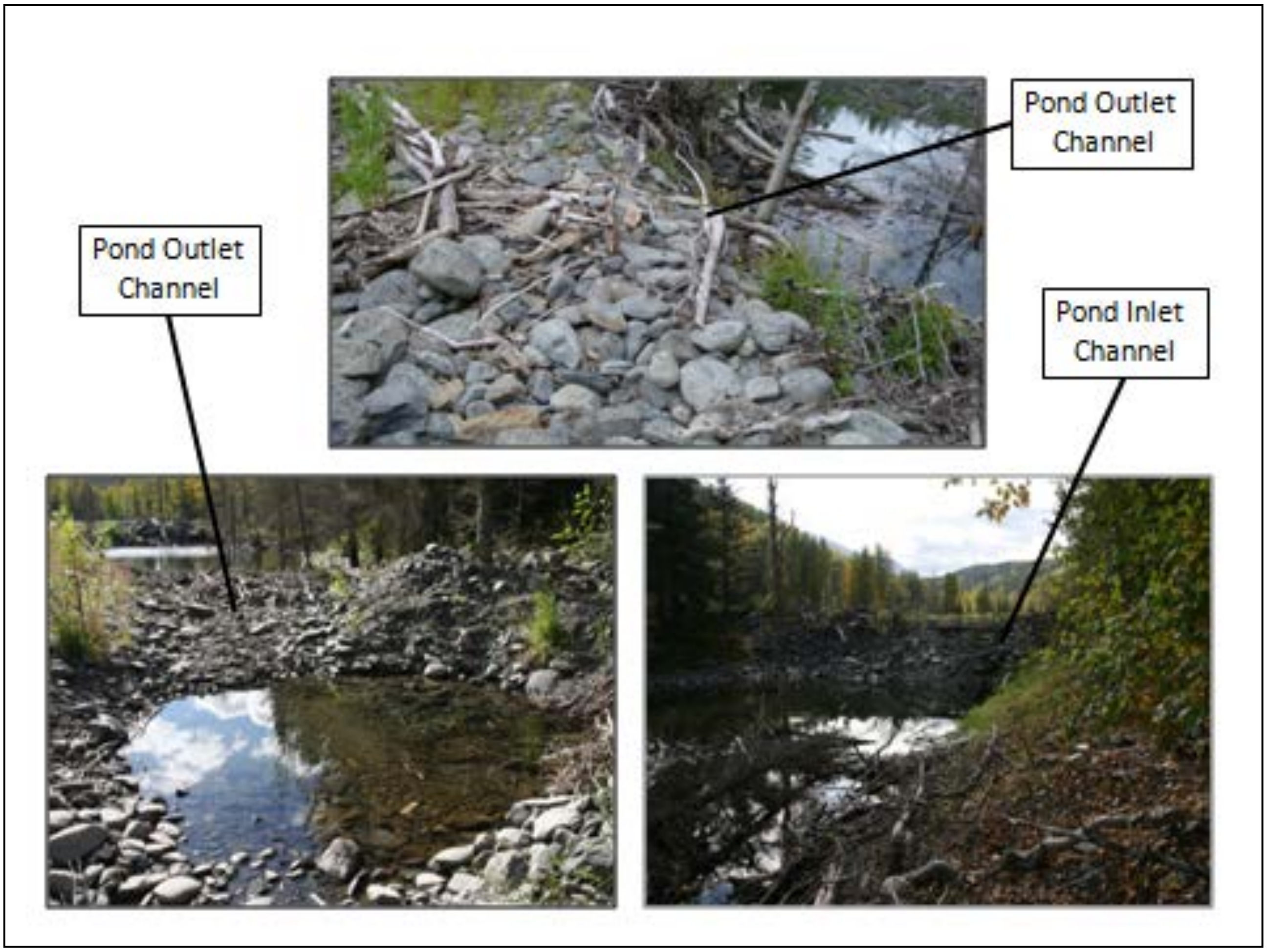
B.6: Side-channel pool below the outlet to Pond 3 during high flow in June (left) and during low flow in September (right).

B.7: Main-stem alcove during high flow in June (left) and during low flow in September (right). Water levels in the alcove were much lower in September.

B.8: Main-stem 1 pool habitat located below pond 1 during high flow in June (left) and low flow in September (right). Water levels in the main-stem channel were much lower in September.

B.9: Main-stem 2 pool habitat located above pond 3 during high flow in June (left) and low flow in September (right). Water levels in this habitat did not change substantially from June to September.

B.10: Steep, shallow, and fast flowing pond inlets.

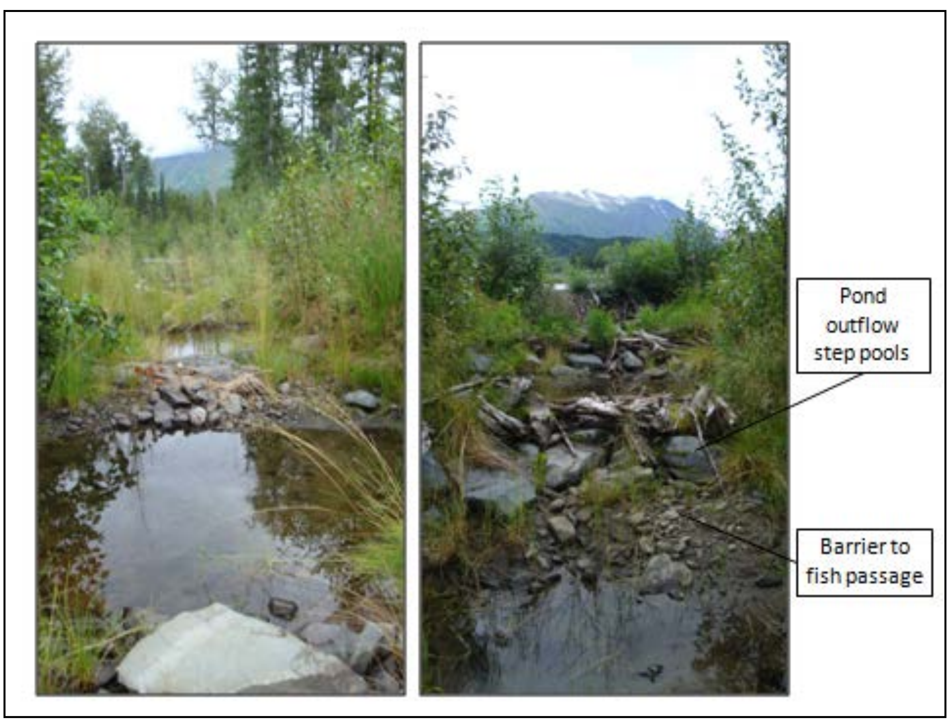


B.11: Pond inlets and outlets impounded by large boulders, cobble, and woody debris during low flow months.

Quartz Creek Pictures

B.12: Aerial Image of Quartz Creek Pond and artificial outflow channel (Ballard 2003). There is no surface water inflow or riparian vegetation around the pond shoreline to provide shade.

B.13: Beaver dam isolating the pond from its outflow channel.



B.14: Exposed step-pools in the pond outlet channel blocking fish access to the habitat.

Little Campbell Creek Pictures

B.15: The alcove channel wrapping around vegetated islands. An oily sheen was observed at the back of the alcove nearest the road.

Eklutna River Pictures

B.16: Pond 1 in August (left) and September (right).

B.17: Pond 2 in August (left) and in September (right).

B.18: Pond 3 in September.

B.19: Small channel of surface water connecting Pond 3 to a nearby wetland.

B.20: Channel connecting Ponds 1 and 2.

B.21: Wide, deep access channels connecting the Pond 1 to the main-stem channel.