Abundance and survival of coho salmon smolts in the Fish River, Alaska, 2009

Annual report by:

LGL Alaska Research Associates, Inc.

and the

Norton Sound Economic Development Corporation

LGL Report P1038

March, 2010

Abundance and survival of coho salmon smolts in the Fish River, Alaska, 2009

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This report was prepared by M. Nemeth et al., under award from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, administered by the Alaska Department of Fish and Game. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration, the U.S. Department of Commerce, or the Alaska Department of Fish and Game.

Executive Summary

Coho salmon (*Oncorhynchus kisutch*) in the Fish River watershed in northwestern Alaska were studied in 2009 to estimate smolt population abundance. Smolt abundance was estimated for the entire watershed and for one major tributary (the Niukluk River). Additionally, the estimated smolt production per kilometer of estimated rearing habitat was modeled to examine habitat influences. Concurrent with the population estimates, survival studies were conducted to assist in explaining for any differences between the modeled and observed smolt abundance estimates. Smolt abundances in 2009 were lower than those predicted based on predictions from parent spawner escapement or from juvenile rearing occupancy models. Complementary data from the nearby Nome River, however, suggests that 2009 may have been an unusually low year for smolt abundance in the region. Possible explanations for the low number of observed smolts are discussed at length, along with study designs for 2010 to help address these explanations.

In 2009, sampling stations were operated from early June through mid July to generate coho salmon smolt abundance estimates for the Fish River watershed, and for the Niukluk River, a sub-population within the watershed. The population estimates were generated using a two-site mark-recapture experiment. Fyke nets were used to capture coho salmon smolts, which were then marked and released. Further downstream, coho salmon smolts were captured using fyke nets and/or a rotary screw trap, where they were examined for presence or absence of marks. The sampling sites in the Niukluk River were in the lower portion of the tributary, near the confluence of the Niukluk and Fish rivers, and were separated by approximately 1 river kilometer. An estimated 34,902 (SE: 7,935) smolts emigrated from the Niukluk River in 2009. Marked fish from the Niukluk River were incorporated into the system-wide population estimate by pooling coho salmon releases from the Niukluk River and the upper Fish River. Coho salmon were then examined for marks at the second sampling event in the lower Fish River, approximately 25 km downstream near the village of White Mountain. An estimated 160,350 (SE: 14,453) coho salmon smolts emigrated from the watershed in 2009. Emigration peaked on July 3 in the Niukluk River, on June 21 at a site nearby in the upper Fish River, and on June 23 in the lower Fish River. Coho salmon captured during this time were almost entirely age-2 fish, and greater than 80 mm in length.

Marine survival of these coho salmon smolts will need to be on the high end of the range reported in the literature (10 – 20%) for adult returns in 2010 to be near the 11-year median of 4,260 adults past the Niukluk River counting tower.

Coded wire tags were injected into 5,008 coho salmon smolts from the Niukluk River to estimate marine survival. The proportion of adult salmon that return in 2010 bearing these tags will be used to compute the marine survival rate of juveniles that emigrated in 2009. A minimum target of 417 adult salmon returning to the Niukluk River will be examined for tags in 2010 to achieve a statistically robust sample.

Estimates of freshwater survival during outmigration in 2009 were attempted, using a longitudinal array of examination sites. In this study, survival from high to low in the watershed was estimated by comparing the recovery rate of two groups of marked fish that differed only with respect to distance traveled. The results yielded an implausibly low survival number (50%) that appeared to be caused, in part, by poor mixing of mark and unmarked fish between sampling sites. These problems may be able to be corrected next year by changing the placement of the sampling stations.

The results from the 2009 field season provide the first empirical data needed for validation of habitat-based production models within the Norton Sound region, outside of the Nome River. The smolt population estimates, given reasonable assumptions of marine survival, could generate adult returns in 2010 that are in line with historic levels. However, the predictions based upon the assumed amount of available rearing habitat, were not accurate. The first step in generating empirical estimates of marine survival was also made by injecting coded wire tags in 5,000 emigrating smolts. Freshwater survival estimates were unsuccessful, but may be possible in future years using information acquired in this first year.

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Introduction

The influence of stream habitat on coho salmon smolt production and eventual adult returns

The extended freshwater residence time of coho salmon (*Oncorhynchus kisutch*) results in a relatively strong influence of freshwater habitat on coho salmon abundance. Juvenile coho salmon rear in freshwater for up to two years, and the number of juveniles that eventually migrate to sea as smolts has been shown to be a function of the quality and quantity of the freshwater rearing habitat (e.g., Nickelson 1998). The abundance of these smolts then influences the number of adult salmon that return to spawn a year later (Bradford et al. 1997; Shaul et al. 2007). Taken together, this means that the number of adult salmon returning to a system is a function, at least in part, of the quantity and quality of habitat available for rearing juveniles (Bocking and Peacock 2005). Accordingly, fishery managers are now using habitat elements to help establish the number of juvenile coho salmon that can be produced in a watershed, and the number of returning adult salmon needed to produce these juveniles (Bocking and Peacock 2005). In Alaska, returns of adult salmon to the river are termed escapements, and fishery managers often develop escapement goals (EGs) as targets or ranges thought to ensure long term population viability.

In theory, habitat-based management approaches should be useful for species that have relatively long freshwater residences, such as sockeye (*O. nerka*), coho, and Chinook salmon (*O. tshawytscha*) and steelhead trout (*O. mykiss*). In practice, such approaches are currently being used to manage salmon throughout the Pacific Northwest, including Chinook and coho salmon in British Columbia (Bocking and Peacock 2005; Parken et al. 2006), Oregon (Sharr et al. 2000; PFMC 2003), and Washington (Volkhardt et al. 2007). A similar approach has been used for decades to estimate the production capacity of sockeye salmon from rearing lakes (Koenings and Burkett 1987; Shortreed et al. 1999; Nelson et al. 2006). Approaches vary among situations, but all rest on the premise that the production of salmon from freshwater ecosystems is linked to the quantity and quality of habitat within the ecosystem. The strength of this linkage between habitat and production may vary among populations, of course, or potentially be overridden by other biotic or abiotic factors.

Coho salmon have been documented in at least 23 discrete watersheds in the Norton Sound region of northwestern Alaska (ADF&G Anadromous Waters Catalog 2009), but so little is known about the size and annual variability of these populations that the number of adults needed for long-term population viability is not known for most of these watersheds. There are currently escapement goals in place for three coho salmon populations in Norton Sound, and adult assessment projects in place for another eight (Brannian et al. 2006). Recent studies in the Nome River indicate that habitat-based models developed in the Pacific Northwest appear capable of accurately predicting a range of smolts that can be produced by the Nome River (Nemeth et al. 2009). The quantity of smolts predicted by the model would generate the 5-year average adult escapement level, given reasonable assumptions of marine survival. If such relationships hold true for other Norton Sound rivers, it may be possible to use habitat to predict smolts, and in turn compute the number of returning adults needed to fully seed a watershed with juveniles (e.g., Nickelson 1998; Bocking and Peacock 2005). This relationship, however, should be tested across divergent systems with differences in habitat to account for watershed diversity within Norton Sound.

The Fish River was selected as a candidate stream for testing habitat-based approaches because of its large size (compared to the Nome River), the presence of a long-term dataset for adult salmon, because it consists of two branches with qualitatively different types of habitat, and because recent low adult escapements have led to speculation that it may have freshwater conditions different from other regional rivers. If habitat-based approaches are transferable to this river, it would increase the confidence that such an approach may be useful across a range of rivers in the Norton Sound region.

We thus proposed a study on the Fish River to test the hypothesis that habitat-based models suitable for the Nome River can effectively predict coho salmon production among watersheds with moderately different habitat types – i.e., that predictor variables related to watershed size exert enough influence over production to override internal differences in habitat types. Concurrently, this study was designed to estimate survival of smolts in fresh and marine waters to help explain the results from the production model and to provide the model inputs needed to link smolt abundance to adult returns. Freshwater survival rates will help explain differences between expected and observed production of outmigrating smolts. Marine survival rates will help explain differences between expected and observed returns of adult salmon, based on the number of emigrating smolts. Finally, the study was designed to be able to compare smolt production and marine survival to the nearby Nome River, where coho salmon smolts were also being studied.

Salmon escapement goals in Norton Sound, and the development of alternative methods or interim assessments

Salmon escapement goals for rivers in the Norton Sound region of northwestern Alaska have been developed using stock recruit data or annual escapement counts, both of which require monitoring projects to count annual adult returns for many consecutive years (e.g., >10 years). Of the 32 escapement goals in existence in Norton Sound, only three are for coho salmon (Brannian et al. 2006). There are currently coho salmon monitoring projects on eight other rivers, but it will take several more years of fish counts to acquire the data needed to develop EGs on these streams. Once developed, the EGs will not be applicable to other rivers; instead, river-specific counts will be needed for each new goal. It will take many more years of salmon counts at relatively high cost to develop EGs on the numerous rivers in Norton Sound. Despite these drawbacks, EGs are seen as critical to the long-term sustainability of salmon populations in Alaska, and the ADF&G has a mandate to develop such goals where possible. Although goal ranges cannot be managed for on all rivers (because of an inability to control harvests or to assess escapement), rivers with assessment projects in place can at least have lower bound goals as an interim step to developing a full goal range.

One alternative to the methods currently in use is to test some of the habitat-based approaches used elsewhere and, if promising, apply these in a variety ways. On the Alaska Peninsula, for example, habitat-based methods have been used to corroborate EGs for Chinook (Nelson et al. 2006) and sockeye (Witteveen et al. 2009) salmon that had been developed using the more standard stock-recruit relationships. In Norton Sound, habitat approaches for coho salmon could be similarly compared to the three existing escapement goals (North, Kwiniuk, and Niukluk rivers) as a preliminary validation. If accurate, the application could be expanded to the remaining streams where coho salmon are currently monitored, but for which escapement goals have not yet been established. The benefits of using a habitat-based approach would ultimately be to provide escapement management tools that do not require developing numerous, consecutive annual datasets for multiple rivers.

Such model testing was the impetus behind a habitat-based analysis of the North and Nome rivers using a combination of literature and empirical data (Nemeth et al. 2009). Based on the observed amount of rearing habitat in each stream, and literature values for smolt production per km of stream, a range of smolts produced in each system was estimated. When empirical estimates of marine survival and fecundity from Norton Sound were combined with literature values for freshwater survival, the estimated number of adults needed to produce the predicted number of smolts was well matched with historic escapements. The investigators then tested smolt abundance models by conducting a multi-year study on the Nome River to compare the observed vs. predicted number of smolts produced from the system (Williams et al. 2009; Nemeth et al. 2009). Estimated production in the Nome River ranged from 413 to 1,423 smolts produced per km of known rearing habitat from 2005 through 2009 (Williams et al. 2009), based on an estimated 81 km of available rearing habitat (Nemeth et al. 2009). This production per km is within the range observed in streams in Washington and Oregon (Nemeth et al. 2009, using data presented in Bradford et al. 1997).

Background on coho salmon in the Fish River and Norton Sound region

The Fish River was chosen for a habitat-based production study because it has numerous years of adult escapement data, differs from the Nome River in terms of size and habitat, and has contrasting habitat between two major internal subdrainages. In addition, the Fish River is of especially high interest to resource managers because it has a coho salmon fishery that is in relatively high demand. It is the largest river in the region by water volume, and produces high numbers of coho salmon, pink salmon (*O. gorbuscha*), and chum salmon (*O. keta*). The salmon population supports a small marine commercial fishery in Golovin Bay and a subsistence fishery in the villages of Golovin, White Mountain, and Council. Harvest pressure can come both from the local communities and, in a situation unusual in Norton Sound, from surrounding communities able to access the river via a road system. This road access includes the city of Nome, the largest population center in the region. As of 2005, over 50% of the coho salmon harvested recreationally on the entire Seward Peninsula came from the Niukluk River (Scanlon and DeCicco 2009). The number of coho salmon spawners needed for long-term sustainability in the Fish River is of special interest because of this potential for heavy demand for salmon in the watershed.

Relative to other rivers in the region the Fish River has a variety of habitats. The two major tributaries in the upper watershed differ to some degree, with the eastern branch (the upper Fish River) having more low-gradient, high-volume water with more forested banks and the western branch (the Niukluk River) having water that is relatively higher-gradient and lower volume water with less forested banks. Although coho salmon returns to most Norton Sound rivers covary due to experiencing similar climatic and oceanic conditions, returns to the Niukluk River have sometimes been out of phase with other regional rivers. All rivers in the region, for example, experienced sharp declines in adult coho returns in 2003, and relatively high abundances from 2006 through 2008. In 2004 and 2005 Niukluk River returns remained low although they returned to normal in nearby systems (Eldorado, Nome, Kwiniuk, and Snake). Overall, coho salmon returns have been at near-record levels in Norton Sound since 2005 (Hilsinger and Swanton 2009), but the Niukluk River population continues to be more variable than other populations (e.g., data presented in Soong et al. 2008).

Goals and Objectives

Prompted by low coho salmon counts on Niukluk River from 2003 through 2006 and the potential for unusually high harvest demand within the watershed, the ADF&G, the Norton Sound Economic Development Corporation (NSEDC), and LGL Alaska Research Associates, Inc. (LGL) met in early 2007 to discuss research needs for the Fish River. The topic of greatest interest was whether habitat-based approaches could accurately predict smolt production, and whether Fish River coho salmon were unusual in terms of juvenile rearing density, growth, or survival. In response, the group designed this project to evaluate the usefulness of habitat-based production models while concurrently measuring actual smolt production and survival in the watershed. The study would predict the number of adults that would likely result from habitat-based estimates of smolt production, test these predictions against empirical data collected over time, and conduct survival studies to help explain the results. These goals would be phased in over the three-year period from 2008 through 2010. In 2009, the specific objectives were to:

1. Estimate the number of coho salmon smolts produced in the Fish River, and in the largest tributary (the Niukluk River);
2. Estimate the freshwater survival of coho salmon smolts as they migrate from upper to lower portions of the drainage; and,
3. Estimate the marine survival of coho salmon smolts emigrating in 2009, by placing tags that will be examined in adults returning in 2010.

Study Area

Fish River watershed

The Fish River is located on the southern Seward Peninsula of Alaska; the mouth of the Fish River is located 100 km east of the city of Nome. The village of White Mountain is approximately 13.5 km upstream of the mouth, on the mainstem Fish River. The village of Council is located upstream on the Niukluk River, which is the largest tributary to the Fish River. The village of Council is approximately 20 km upstream from the confluence of the Fish and Niukluk rivers, and is on a road system connected to Nome and other nearby communities (Figure 1).

The Fish River is a 6^{th} order stream on the Strahler scale at 1:24,000. The watershed drains an area of 5,892 km^2 and is 146 km long. Although water discharge records are not available, it is one of the largest rivers on the southern Seward Peninsula. The watershed is unglaciated. Water levels peak in the spring from snowmelt and again in the fall from rain.

The upper watershed is split into western (the Niukluk River) and eastern (the upper Fish River) branches (Figure 2). The upper Fish River begins in the Bendeleben and Darby mountains and flows southwest through a relatively vegetated landscape dominated by tussock tundra, sedges, and low shrubs. The dominant geology is Quaternary deposits. The Niukluk River, by contrast, arises in the western Bendeleben Mountains, flows southwest then southeast, and has a dominant geology of Precambrian rocks. The Niukluk River is 96 km long and drains 2,263 km^2. Water discharge records are not available.

The two upper branches converge about 37.5 km upstream from the ocean to form the mainstem Fish River, then add one additional major tributary (the Fox River) before emptying into Golovin Bay. This section of river is relatively low gradient and high volume, with side sloughs and islands and often surrounded by forest.

Geology

Most of the geology in the Fish River drainage is comprised of stratified sedimentary rocks or deposits. The upper Fish River flows through three distinct geologic sections: older Precambrian rocks, Quaternary deposits, and younger Precambrian rocks (Beikman 1980). The geology of the Niukluk River drainage contrasts that of the upper Fish River and consists of Precambrian rocks, undifferentiated volcanic rocks, and Paleozoic rocks.

The Bendeleben and Darby mountains are mostly older Precambrian with some felsic deposits as well (Beikman 1980). After the mountains, the river flows through Quaternary deposits composed of alluvial, glacial, beach or lake deposits. The river then flows through younger Precambrian rocks (schistose and dolomitic limestone) until about the confluence with the Niukluk River.

The Niukluk River drainage is mostly Precambrian rock and undifferentiated volcanic rock (Beikman 1980). There are also localized concentrations of Paleozoic rocks throughout the drainage.

After the confluence of the Niukluk and upper Fish rivers, the dominant composition is Devonian rocks and Precambrian rocks, fairly similar to the geology of the Niukluk River drainage (Beikman 1980).

Vegetation

Vegetation in the Fish River drainage varies greatly, due to a variety of factors ranging from differing geological conditions, soil types, and changes in elevation. These environmental influences produce tussock tundra, marsh wetlands, hillside glades, and spruce forests within close proximity. The upper Fish River differs from the Niukluk River drainage in having much more wetlands and tundra (Swanson et al. 1985).

Vegetation in the upper Fish River is largely dependent on the elevation. In the higher elevations, the vegetation ranges from forests to alpine plants. Dominant vegetation includes mountain-avens (*Dryas spp.*), grasses (*Carex spp.*), birches (*Betula spp.*), willows (*Salix spp.*), alpine azalea (*Loiseleuria procumbens*), mosses (*Ptilium spp.* and *Hylocomnium spp.*) and lichens (*Cladina spp.*and *Centraria spp.*; Swanson et al. 1985). Continuing downstream, dominant species include tussock cotton grass (*Eriophorum vaginatum*), northern Labrador tea (*Ledum decumbens*), lingonberry (*Vaccinium vitis-idaea*), grasses, dwarf birch (*Betula nana*, willows, green alder (*Alnus crispa*), mosses (*Polytrichum spp.* and *Sphagnum spp.*), and lichens.

Although vegetation comparisons do not exist, the Niukluk River subdrainage appears to have a lower proportion of forest coverage than the upper Fish River. In the Niukluk River drainage, vegetation is similar to that of the upper Fish River, though tussock tundra is less common (Swanson et al. 1985). Stands of white spruce (*Picea glauca*) dominate hillsides while at lower elevations balsam poplar (*Populus balsamifera*) is widespread. Diamondleaf willow (*Salix planifolia*) and green alder (*Alnus crispa*) are most common in the understory. Mountaintops have the same species composition as in the upper Fish River; mountain-avens, dwarf birches, and lichens are the most common vegetation.

Downstream of the Niukluk River confluence, the lower Fish River is predominately a mixed forest floodplain interspersed with tundra tussocks (Swanson et al. 1985). Trees surrounding the floodplain are a mixed forest made of willow, spruce, alder, and balsam poplar. Tundra tussocks are predominately made of grasses, dwarf birches, mosses and lichens.

Adult Salmon escapement and harvest monitoring

The Fish River supports all five species of Pacific salmon found in Alaska. Since 1995, the ADF&G has operated a counting tower on the Niukluk River, located 40 km upstream from saltwater, to monitor adult salmon escapement. Counts of Chinook, sockeye, and pink salmon are indices because the proportion of each that spawn below the tower or migrate up the other main branch of the watershed (the upper Fish River) is unknown. Counts of chum and coho salmon are used primarily as an index to compare among years (as with Chinook, sockeye, and pink salmon), but can also be used to estimate escapement to the entire watershed, using proportions derived from radio telemetry studies. The lower escapement goal limit of 2,400 adult coho salmon has been exceeded in 8 of the past 10 years; the upper limit of 5,900 adults has been exceeded in 5 of those 10 years (Table 1; escapement data from Kent et al. 2008 and J. Menard, ADF&G, personal communication). In 2010, the upper limit was been proposed to be raised to 7,200 (Volk et al., *in press*). The Niukluk River receives an estimated 35 to 41% of the coho salmon returning to the entire watershed (Table 2), although these numbers likely do not reflect the full range of variability in the tributary proportions (because they were taken from two individual telemetry studies conducted in consecutive years; Todd and Balland in prep).

Adult coho salmon return to the watershed from July to September, with the run usually peaking around mid-August (Scanlon 2009). All of these coho migrated as smolts the previous spring, and have thus spent approximately 15 months at sea. Based on average scale ages collected from returning adults in the Niukluk River, approximately 12.7% of these had spent one winter as juveniles in freshwater, 84.7% had spent two winters, and 2.6% had spent three winters (Kent 2006, 2007; Kohler and Todd 2003; Rob 1997, 1998). Therefore the adult coho salmon run in 2009 was composed of fish that originally hatched in the spring of 2006 (and then spent two years in freshwater), but also fish that hatched in 2005 and 2007. All three of these age groups had emigrated as smolts in the spring of 2008.

Sampling locations

Sampling sites for this study were established in three main areas of the river: the Niukluk River, the upper Fish River upstream of the confluence with the Niukluk River, and the lower mainstem Fish River. The Niukluk River sites consisted of a pair of sampling stations in an upstream-downstream configuration. Fish captured in the upper Fish River were marked and released to add to the sample size used to generate the population estimate for the entire watershed. Downstream, these fish were exposed to capture at the second group of sites (the lower mainstem Fish River sites), which allowed a population estimate for the entire watershed.

Sampling sites – Niukluk River and upper Fish River

The Niukluk River sites were split into two main sampling areas, one for the fin mark placement (Site A1, 4.2 km upstream from the Fish River confluence) and one for the fin mark recovery (Site A2, 3.2 km upstream from the Fish River confluence). Fyke nets at these sampling locations were adjusted or moved as water conditions changed. For a short stretch of time, a second net was operated at the upper area (Site A1) to increase the sample size. Overall, these sites were used as the full mark-recapture sites needed for the population estimate within the Niukluk River, to place some of the marks used for the watershed-wide population estimate, to place some of the marks needed for the freshwater survival study, and to place all of the coded wire tags needed for the marine survival study.

The upper Fish River sampling area consisted of one fyke net that was operated in the same location for the entirety of the season. This site (A3) was 2.6 km upstream from the confluence with the Niukluk River (Table 3). Fish at Site A3 were marked with fin clips, but coded wire tags were not implanted. Overall, this site was used to contribute some of the marks needed for the watershed-wide population estimate, and for the freshwater survival study.

Sites A1, A2, and A3 were maintained by a crew housed at the tower enumeration camp site maintained by the ADF&G since 2006. Crews traveled to the sampling locations using a jet boat.

Sampling sites – lower Fish River

In the lower Fish River, sampling was split into two areas, identified as sites B and C. Site B consisted of a rotary screw trap that was used to capture fish throughout the entire season. Coho salmon smolts captured at this site were inspected for marks placed upstream, then given an additional mark for later inspection downstream (at the C sampling area). This site was 17.8 km upstream from the mouth of the Fish River (Table 3 Distance Upstream). The B site was used as one element of the freshwater survival portion of the study.

Site C consisted of two fyke nets (sites C1 and C2), one on each side of the river, operated similarly to the fyke nets used upriver. Site C1 was 15.3 km upstream from the ocean (and 2.5 km downstream from site B). Site C2 was 1.0 km upstream from C1. Coho salmon captured at these nets were inspected for marks, but not marked further. The C sites were used as the recapture portion of the watershed-wide population estimate, and the freshwater survival estimate.

Methods

Sampling gear

Fyke nets are a stationary, passive fishing gear that can fish continuously and are capable of catching large numbers of fish in the targeted size ranges for coho salmon on this project (Wiliams et al. 2009). Fish moving downstream were directed into the fyke net trap, which had a mouth opening that measured 1.7 m by 1.8 m of stainless steel and which was faced with 0.64 cm stretched mesh netting. Two meter deep wings extended out from either side of the trap mouth to help funnel fish into the trap. One wing was made of 1.27 cm stretch mesh netting and extended 15 m to shore at an upstream angle of approximately 45°. The second wing extended out toward the thalweg of the river at a more acute angle; this wing was also 15 m long and made of 1.27 cm stretched mesh netting, or in some cases was made of 1.27 cm Vexar ©. The nets were supported by steel pipe 3.8 cm in diameter (Photos 1 and 2).

Ideally, fyke nets were placed in water about 1.0 – 1.2 m deep, though the wings could extend into water up to 2 m deep. Nets were adjusted with fluctuating water levels as necessary to sample as much of the thalweg as possible. If it was necessary to move a net to a different location, then the exact location was noted and given a unique code for future reference.

The rotary screw trap (RST) was manufactured by EG Solutions (Corvallis, OR), and consisted of an 2.4 m diameter drum mounted on pontoons measuring 0.6 m wide by 0.28 m tall by 7.0 m long. The trap was able to fish at depths up to 1.2 m below the surface of the water. The RST was anchored in place using lines attached to shore or to a Danforth anchor placed in the riverbed. The RST operated just downstream from the outside of a river bend and next to shore to minimize interference with local boat traffic (Photos 3 and 4). A three meter log boom was sometimes used to funnel in more fish into the trap. The RST was adjusted as necessary to maintain target operating speeds of 6 to 9 RPM.

Minnow (gee) traps were used to supplement catches. Each minnow trap used was a standard trap consisting of two cones end-to-end. Traps were baited with salmon eggs sterilized with a 1:100 betadyne solution. Minnow traps were set near existing gear sites and were only used in the Niukluk River and lower Fish River. The traps wire mesh had 0.64 cm openings, allowing only larger fish to remain in the traps. To reduce the chance of fish escaping, minnow traps were checked more frequently than other gear types.

Fish processing

Fish biosampling

All sites were checked at least twice a day. Upon arrival to a sampling site, crews first removed fish from the gear and kept them in-stream in a floating net pen made of 0.32 cm nylon mesh (Photo 5). All fish were identified to species and counted. Random samples of up to 30 coho salmon were taken at all sampling sites during every sampling event. This randomly selected group was used to obtain fish length measurements (every subsample), weights (two subsamples per week) and scales used to age the fish (throughout the week, following a weekly scale quota for different size groups). Lengths were taken to the nearest millimeter measuring from the tip of the nose to the fork of the tail (TFL; Photo 6), and weights were taken to the nearest 0.1 g. Only coho salmon ≥60 mm were sampled for age. If fish were to be coded wire tagged, they were set aside and given a mild anesthetic of clove oil immersed in ethanol solution (9:1 ethanol to clove oil).

After biosampling, fish were quickly returned to the river, downstream of the trap and in slow water, preferably in areas with cover. If predatory fish were noticed in the area, the release site was moved. Fish that were anesthetized were monitored until able to swim under their own power, and then released.

Catch per unit effort (CPUE) of each gear type was calculated as the number of fish collected per 24 hours of fishing effort. Fish CPUE, age, length, and weight were used to analyze run timing, estimate age and length composition, and evaluate fish body condition.

Coho salmon smolt population estimates

Population estimates of coho salmon smolts were calculated for the Fish River drainage and the Niukluk River using two separate two-site mark-recapture studies. The general design of a two-site mark recapture study for salmon smolts is to mark fish at one location, and then examine all fish caught at a recapture location that is downstream from the marking location. The abundance estimates were then a function of the number of marked fish released, and the ratio of marked to unmarked fish sampled at the recapture location. The Niukluk River population estimate was generated using fish marked at site A1 and examined at site A2. The population estimate for the Fish River was generated from marked releases in the Niukluk River (sites A1 and A2) and the upper Fish River (Site A3), then examined at the lower Fish River (sites B and C pooled together). Because of the potential for immigration between the mark and recapture site, the population estimates are applicable to the recapture site, not the original mark site (e.g., the lower Fish River, not the upper Fish River).

Smolt classification

Salmon smolts are by definition migrating out of the river to sea and are therefore susceptible to being recaptured downstream from a marking location. Because smolts were the only life stage sure to be moving past each recapture site after release, special attention was devoted to determining which combination of fish size, age, and run timing represented smolts and pre-smolts. Once identified, pre-smolts could be removed from the dataset and the population estimate generated only with smolts.

Juvenile coho salmon captured were thus examined for a silvery condition indicative of smoltification. During smoltification, a series of physiological, behavioral, and morphological changes occur for fish to adapt from a life in freshwater to a life at sea (Wedemeyer 1996). As smoltification begins, fish develop a silvery appearance, with the parr marks (dark vertical lines on their body) becoming less prominent (Eales 1969) and their bodies becoming more streamlined. Smoltification status was combined with length and age information from the sampling events to generate classification of size groups by date range that were likely to be smolts (e.g., Nemeth et al. 2009; Williams et al. 2009).

Marking protocol

Before the season, the likely minimum size of smolts was identified as 80 mm based on smolts captured in prior years in the Nome River (Williams et al. 2009). Therefore, temporary caudal fin marks were applied to all coho salmon ≥80 mm in length at sites A and Site B. The exact mark type was varied by sampling location. In the Niukluk and upper Fish rivers, marks were alternated between a lower and upper caudal clip every seven days. This alternation of the mark types allowed for temporal stratification of the mark groups in case capture efficiency changed at the recapture sites, and also allowed calculation of travel time from the release to recapture sites.

All juvenile coho salmon were examined for marks at the lower Niukluk River site (A2) and all sites in the lower Fish River. The number of marked and unmarked fish captured and the mark types were recorded at each sampling event. Any recaptures were measured for fork length to the nearest millimeter. All coho salmon smolts caught at Site B (the RST) were given an additional mark (temporary caudal fin mark) for inclusion in the freshwater survival estimate. Fish caught at the Site C (the nets farthest downstream) were examined for marks but not given any additional mark.

Mark-recapture model selection

Two mark-recapture models were considered for estimating the smolt abundance in the Niukluk River and the Fish River. Model selection was based on results of tests of equal probability of the recapture of marked fish through time. If recapture probabilities were equal, all data throughout the season were pooled and the pooled Petersen estimate (PPE), with Chapman's modification (Seber 1982) was used. If recapture probabilities were not equal through time, the data were partially stratified into groups with similar capture probabilities over time, and population estimates were then generated using a Darroch model (Darroch 1961). Models were fit using the software SPAS (Arnason et al. 1996). Thorough descriptions of both models are provided by Schwarz and Taylor (1998).

Prior to model selection, fish were stratified into size classes *post hoc* based on the minimum and maximum lengths common to the mark and recapture sites, and by any differences in size selectivity between the two types of gear (fyke nets and RST).

Notation for variables in the mark-recapture models were as follows:

n_1 = marks released
n_2 = fish examined for marks at the second sample event
m_2 = recaptures in the second sample event
u_2 = number of fish without tags in the second sample event
p_1 = probability of capture at time 1 = m_2/n_2
p_2 = probability of capture at time 2 = m_2/n_1
$\hat{N}$ = population abundance estimate

Pooled Petersen estimate – calculations and assumptions

The Pooled Petersen estimate with Chapman's bias correction (PPE; Seber 1982) was calculated as

$$\hat{N} = \frac{(n_1 + 1)(n_2 + 1)}{m_2 + 1}$$

The assumptions required for the population estimates to be unbiased were as follows (Seber 1982):

Assumption 1: closed population

Fish migrating from outside of the marking pool has the same effect on the population estimate as would recruitment, rendering the estimate germane to the recapture sites.

We assumed no mortality due to the marking process and no appreciable natural mortality between the marking and recapture sites. Mortality due to marking was thought to be negligible because fish were able to be marked quickly and with a minimal amount of handling (approximately 5 seconds per fish to identify to species and mark). On the Nome River, the investigators have detected minimal latent mortality in coho salmon after tagging with coded wire tags (Williams et al. 2009). Travel time for smolts was over a short period of time, during a life history stage when mortality is relatively low; thus, the potential for natural mortality between the upper and lower sites was small. This assumption was also tested as part of Objective 2 (freshwater survival).

Average travel time from the upper sites to the lower sites was computed to help assess evidence of injury manifested in the form of unusually slow migration time. Travel time from the marking sites to the recovery sites was modeled as a Poisson distribution, which is typically used for count type data and can be described with one parameter. The lag time (i.e., the one parameter = the expected value from the Poisson distribution) between the number of fish released and the number recaptured, as well as the recapture rate were adjusted (parameterized) to minimize the sum of square differences between the number of recoveries observed and the number predicted.

Assumption 2: probability of marking was constant

Because we did not capture every smolt, the probability of capture at the marking site (p_1) was not constant across all migrating smolts.

Assumption 3: equal catchability for marked and unmarked fish

Validating this assumption was not possible, but we considered it unlikely that marking affected catchability at the recapture site because 1) the marks and fish handling were chosen based in large part on strategies that would minimize effects on fish, and 2) the use of different gear types at the mark and recapture sites would eliminate any learned aversion to specific gear by marked fish.

Assumption 4: probability of capture was constant or marked fish mix uniformly with unmarked fish (or both)

Fluctuating water levels can change the capture efficiencies of the gear types, causing p_2 to vary among individuals migrating at different times. Any observed changes in capture probabilities, as well as lack of mixing, through time were addressed by way of partial stratification. Likewise, differences in capture probabilities across body sizes were corrected with size-stratified estimates. The Kolmogorov-Smirnov two-sample test (KS test; Conover 1971) was used to detect if size selective sampling occurred during the second sampling event. The cumulative length frequency distribution of all fish marked during the first event (n_1) was compared to that of marked fish recaptured during the second event (m_2). If the length distributions were significantly different (D statistic: the maximum absolute difference between the cumulative distributions), then releases and recaptures were stratified by the D statistic as the cut point for stratification. That is, separate abundance estimates would be developed for fish groups delineated by the size cut point. Using the location of the D statistic as the cut point ensures that the differences between two strata with respect to p_2 were maximized, and in so doing homogeneity of p_2 within each size stratum was also achieved.

Assumption 5: tags were not lost and marked fish survived to the recapture site

The evaluation of marked fish travel times from the upper sites to the lower sites was used to determine if there was enough time between sites for regeneration to occur, thereby causing a loss of marks. Travel time of marked fish between sites was estimated to help assess whether fish had a relatively long or short exposure to natural mortality from sources such as predation. Fish marking and handling procedures were designed to be less invasive than other marking studies that have caused little short-term mortality (e.g., annual monitoring on the Nome River that applies the same marks, along with code wire tag implants; Williams et al. 2009).

Assumption 6: tags were recognized and reported

All fish captured in the lower sites were handled and inspected individually to keep the probability of missing marks to a minimum. Furthermore, the number of fish handled during individual site visits was generally low and the marks easily recognized.

Mixing test

Initial temporal strata were preset based on the dates fin clips were altered. Any pooling of rows was guided by similar p_1 values estimated for each cell, and columns were pooled based on similar p_2 values across cells. The only pooling requirement was that the matrix either be square (number of tagging strata = number of recovery strata) or the number of tagging strata be greater than recovery strata in order for the estimate to be applicable to the recapture site (Schwarz and Taylor 1998)**.** If a non-significant Chi-square test resulted from any of the following three tests ($\alpha = 0.05$), then the PPE model was chosen.

Tagging stratum	Recovered	Not seen again
S1	$m_{2,S1,.}$	$n_1 - m_{2,S1,.}$
S2	$m_{2,S2,.}$	$n_1 - m_{2,S2,.}$
S3	$m_{2,S3,.}$	$n_1 - m_{2,S3,.}$
S4	$m_{2,S4,.}$	$n_1 - m_{2,S4,.}$

Equal proportions test

	Recovery strata			
	R1	R2	R3	R4
Marked	$m_{2,.,R1}$	$m_{2,.,R2}$	$m_{2,.,R3}$	$m_{2,.,R4}$
Not marked	$u_{2,.,R1}$	$u_{2,.,R2}$	$u_{2,.,R3}$	$u_{2,.,R4}$

Equal movement test

Tagging	Recovery strata				
stratum	R1	R2	R3	R4	Not seen again
S1	$m_{2,S1,R1}$	$m_{2,S1,R2}$	$m_{2,S1,R3}$	$m_{2,S1,R4}$	$n_1 - m_{2,S1,.}$
S2	$m_{2,S2, R1}$	$m_{2,S2, R2}$	$m_{2,S2, R3}$	$m_{2,S2, R4}$	$n_1 - m_{2,S2,.}$
S3	$m_{2,S3, R1}$	$m_{2,S3, R2}$	$m_{2,S3, R3}$	$m_{2,S3, R4}$	$n_1 - m_{2,S3,.}$
S4	$m_{2,S4, R1}$	$m_{2,S4, R2}$	$m_{2,S4, R3}$	$m_{2,S4, R4}$	$n_1 - m_{2,S4,.}$

Travel times

Fish travel times were examined with three models, which were based upon constant travel time, density grouping travel, and variable rate travel times. The model results were compared with the Akaike information criterion (AIC; Akaike 1973), corrected for a small sample size, AICc (Burnham and Anderson 1998), as a means for selecting the most parsimonious model. Comparing AICc weights would determine which model best fit the data, with the lowest AICc value indicating the best fit.

Freshwater survival from upriver to downriver

Conceptually, the survival estimation works as follows: Fish released at site A will be recaptured at site C if they survive capture, handling, release, movement between point A and B, movement between point B and C, and if they encounter and are entrained in capture gear at C. Fish released at site B will be recaptured at site C if all of the above conditions apply, except that they do not move from point A to B. Thus, if all else is equal between release groups (capture, handling and release survival; recapture probability at C; and survival from B to C are the same for both groups), then the fish released at B act as a control group for those released at A (the only difference between them is the fact that one group moved from A to B and the other did not).

$$\mathrm{S_{AC}} = \frac{\text{Marks recaptured from Site A at Site C}}{\text{Marks released at Site A}}$$

$$\mathrm{S_{BC}} = \frac{\text{Marks recaptured from Site B at Site C}}{\text{Marks released at Site B}}$$

Survival from A to B is thus calculated as the ratio:

$$S_{AB} = {S_{AC}}/{S_{BC}}$$

The variance of the survival estimate is calculated as:

$$VAR(S_{AB}) = \frac{{S_{AC}}^2}{{S_{BC}}^2}\left(\frac{(1-S_{AC}){n_A}^{-1}}{S_{AC}} + \frac{(1-S_{BC}){n_B}^{-1}}{S_{BC}}\right)$$

where n_A and n_B are the number of fish marked and released at sites A and B, respectively.

This methodology is similar to that used to estimate smolt survival through hydropower projects in the Columbia and Snake rivers (e.g., Skalski et al. 1998; originally developed by Burnham et al. 1987; English and Labelle 1999; English et al. 2001; Robichaud et al. 2003a, b).

Marine survival

Coded wire tagging

Coho salmon smolts in the Niukluk River were implanted with coded wire tags (CWT). Fish to be tagged were captured in the course of the normal sampling with fyke nets and minnow traps; fish of presumed smolt size (≥80 mm) were selected for tagging. All fish to be tagged were slightly anesthetized for easier handling and to reduce stress on the fish, and a tag was then injected into the tip of the snout using a Mark IV tag injector from Northwest Marine Technology® (NMT; Photo 7). After tagging, coho salmon smolts were checked for tag presence with an electronic CWT scanner (from NMT). If a fish was given a CWT the adipose fin was removed, in accordance with State regulations. No CWT tags were placed in smolts from the Fish River. Each day, up to 200 coho salmon smolts that were tagged were held for 24 hours to assess latent mortality and tag retention, the total number of tags released was then adjusted to reflect any mortality or tag loss.

Adult coho salmon returning to the Niukluk River in 2010 will be captured with beach seines and checked for adipose clips. Fish with missing adipose fins will be scanned for the presence of a CWT. Marine survival to the Niukluk River will be calculated by applying the mark rate in adults by the number returning to the entire Niukluk River (based on tower counts). Marine survival to the watershed will be estimated by adding in harvest downstream of the Niukluk Tower, if such data are collected by ADF&G. Calculations will be as described for the Nome River by Williams et al. (2009), and will be covered in detail in the next report.

Environmental and fish community monitoring

Environmental data

Water temperatures were taken during each sampling event at each group of sites, using a hand-held alcohol thermometer and recorded to the nearest degree Celsius.

Water depths were also recorded using a meter stick installed at each group of sites, and recorded to the nearest cm during each sampling event. Depth data were standardized to show trends across sites.

Monitoring fish community composition

In addition to coho salmon, lengths were measured from up to 20 randomly selected pink salmon, Chinook salmon, Arctic grayling (*Thymallus arcticus*), and Dolly Varden (*Salvelinus malma*) each day. No clips, weights, or scales were taken on from these fish.

Results

Sampling effort

Upper sites

All fyke nets in the upper sites were sampled twice a day. A single test fyke net was installed in the Niukluk River from June 6 – June 8. Sites A2 and A3 were the first permanent nets placed in the river and were both installed on June 9 and operated until July 8 for 30 total days of operation (Table 4). Site A1A was operational from June 11 – July 8 (28 days). Site A1B was operational from June 14 – July 8 (25 days). No sampling occurred at any sites on July 4. Crews left the nets open on the PM sample on July 3, and made the nets operational again on the evening of July 4.

All nets were moved to adjust for changing water levels. Fyke nets were moved short distances (<5 m) frequently as the water levels fluctuated. Nets were moved greater distances when necessary as water levels dropped throughout the course of the season. The only periods of downtime, when gear was not fishing, was during the times the nets were moved.

Five minnow traps were operated intermittently in the Niukluk River from June 25 – July 3. These traps were located primarily near Site A2, though were continuously moved in the surrounding area to maximize catches.

Lower sites

Sampling of the lower sites occurred twice a day. Site B was the first installed and operated for the entire length of the season (June 6 – July 17). Site FR-Test1 was a trial site in place from June 8 – June 13, 2009 to test the suitability of fyke nets for the sampling location. Site C1 was operational from June 13 – July 17, and Site C2 was operational from June 19 – July 17. From June 20 – June 21 two minnow traps were set in the lower Fish River.

Run timing, age, and body condition

The midpoint (defined as the date that the 50th percentile of fish were caught) of the coho salmon catch was June 23 for the upper sites. The midpoint for the lower sites and all sites combined was June 24 (Figure 3). Catches in the upper Fish River peaked on June 21 at 951 fish/day. Sites in the Niukluk River peaked later on July 3 at 171 fish/day (all Niukluk River sites combined; Figure 4). Lower Fish River CPUE peaked on June 22 at 356 fish/day. When catches peaked, the juvenile coho salmon were almost entirely smolt-sized fish at all sites. Water levels were not strongly correlated with catches in the Niukluk River (Figure 5).

Juvenile coho salmon were generally ≥80 mm (Figure 6). Age data are currently being processed, but based upon observations in other Alaskan rivers (Williams et al. 2009; Nemeth et al. 2009), coho salmon this size are an outmigrating, age-2 smolt. Some age-0 fry (<50 mm) were caught though uncommon. Coho salmon in the size class 50 – 79 mm (age-1) were caught in the least numbers.

Generally, smolts were within a healthy weight range for their length. Lower Fish River smolts weighed the most for a given size, followed by Niukluk River smolts (Figure 7). Upper Fish River smolts were the lightest for their size. Fish River coho salmon mean body condition was 99.3, slightly lower than the 6-year index from the Nome River (set at 100, by definition).

Population estimates

For both the Niukluk and Fish River population estimates the assumptions of constant catchability and/or uniform mixing needed for the PPE were not met, based upon model fits with SPAS software. Therefore, the Darroch estimate was chosen to allow for temporal stratification.

Niukluk River estimate

In total, 2,518 coho salmon smolts were marked at the upper Niukluk River sites (Table 5). Another 3,022 coho salmon smolts were examined at the lower Niukluk River site. Of these, 323 were recaptures. The largest recaptured fish was 165 mm and the smallest recaptured fish was 83 mm; thus the population estimate for the Niukluk River is only for the 83 – 165 mm size class. No significant difference in length was observed between fish released with marks and recaptured with marks. The Niukluk River population estimate is only of those smolts outmigrating from June 12 to July 8.

The total abundance of coho salmon smolts in the Niukluk River in 2009 was estimated to be 34,902, with a standard error of 4,048 (Table 5). There were five marking strata and five recovery strata. Five release and recovery strata were incorporated into the Darroch estimate, partial pooling of the data was used to increase the fit of the data to the model. This resulted in three release groups with release strata 1 and 2 as well as 4 and 5 pooled. Recovery strata 1 and 2 were pooled, resulting in a total of 4 recovery stratum (Table 5).

Fish River estimate

In total, 9,383 coho salmon smolt from the upriver sites were given caudal fin marks (Table 6). At the sites in the lower Fish River, 7,263 coho salmon were examined and of these 425 were marked recaptures.

Recaptured fish ranged in size from 81 – 140 mm. Consequently, the Fish River smolt population estimate was only of fish in this size class. No significant difference in lengths was observed between fish released with marks and recaptured with marks. The lower Fish River gear (recapture sites) operated between June 10 – July 17; the population estimate only pertains to smolts during this time period.

Clips were pooled into temporal strata, each stratum usually lasting a week. Five release strata and six recovery strata were incorporated into the Darroch estimate, and partial pooling of the data was used to increase the fit of the data to the model. This resulted in two release groups one consisting of release strata 1, 2 and 3 and the other consisting of release strata 4, 5 and 6. All recovery strata were pooled, resulting in 1 recovery stratum.

The total abundance of coho salmon smolts in the Fish River watershed in 2009 was estimated to be 160,350, with a standard error of 7,374 (Table 6). Fish downstream of the lower sampling sites were not included in this estimate.

Travel times

Coho salmon smolt travel times were best modeled using the constant travel time model, which estimated travel from the Niukluk Rive to the lower Fish River at 4.5 days, with a range of less than one day up to twelve days (Figure 8). Model estimates for coho salmon smolts traveling from the upper to lower Fish River was three days and ranged from less than one to nine days.

Smolt survival during outmigration

Of the 9,383 marked coho salmon released from Site A (the Niukluk and upper Fish rivers combined) a total of 361 were recaptured at Site C, with a resultant S_{AC} of 0.038. An additional 944 marked coho salmon were released at Site B, of which 72 were recaptured at Site C with a resultant S_{BC} of 0.076. Based upon the ratio of S_{AC} to S_{BC} (equation 3), survival from Site A to Site B (S_{AB}) was calculated to be 0.504 with a variance of 0.014.

Marine survival

Coded wire tagging

Coded wire tags were placed into 5,008 coho salmon smolt in the Niukluk River. Of these, 1,570 were held overnight to assess tag retention. Of those held overnight, three died and 24 lost their tags for an overall tag retention of 98.1%. The adjusted number of viable tags released was 4,947 (Table 7). Almost all coho salmon smolts captured in the Niukluk River were implanted with tags (Figure 9).

Adult salmon in the lower Fish River and the Niukluk River will be examined next year for the presence of a CWT. Based on the adjusted number of tags released (4,947 CWT smolt) and the estimated population size (34,902 coho salmon smolts), at least 418 adult coho salmon will need to be examined in the summer of 2010 (Table 8).

Environmental and fish community monitoring

No species were captured that had not been documented in the region before. Similarly, no species were absent that are found abundantly in nearby watersheds.

The most commonly caught fish were pink salmon fry, making up 33% of all catches (Table 9). Catch of pink salmon fry was highest in the lower Fish River. Pink salmon adult returns were very high in 2008 possibly increasing the number of fry. Pink salmon were not measured for length at the upper sites though a clear trend of growth was observed over the season in the lower Fish River (Figure 10).

Chum salmon were the second most prevalent species (Table 9). More juvenile chum salmon were caught in the lower sites but chum salmon also made up over half of the catch at Site A3. Chum salmon also showed a clear trend of growth over the season (Figure 11).

Among all sites, 17,272 juvenile coho salmon were caught. Others species commonly caught included round whitefish (*Prosopium cylindraceum*), Arctic grayling, Dolly Varden, ninespine stickleback (*Pungitius pungitius*), rainbow smelt (*Osmerus mordax*), sculpins (*Cottus spp.*), burbot (*Lota lota*), and Arctic lamprey (*Lampetra camtschatica*). In all, 19 different species were caught.

The greatest catch diversity was observed in the lower Fish River, where 18 species were captured. Of these, six species were not observed at the upper river sites (Table 10). The Niukluk and upper Fish rivers had similar catch diversity with 12 and 13 species caught, respectively. Lampreys were identified to species only in the Niukluk River. Both Pacific and Arctic lamprey could have been present in the upper Fish River as lampreys were caught there as well (Table 9). Notably, round whitefish and northern pike were caught in the upper Fish River but not in the Niukluk River.

Environmental conditions

Temperatures in the upper and lower Fish River followed each other very closely and were almost always within 1°C (Figure 12). In the lower Fish River, temperatures ranged from 5.3 – 16.6 °C, averaging 11.9 °C. In the upper Fish River, temperatures ranged from 5.3 – 17.5 °C with an average temperature of 11.7 °C. In the Niukluk River, temperatures ranged from 2.7 – 14.3 °C, averaging 8.5 °C. The lower Fish River temperature data logger ran for a longer period of time, covering more of July.

Average daily temperatures in the upper Fish River were warmer than the lower Fish River which was in turn warmer than the Niukluk River. Temperatures at all sites climbed steadily throughout the season, though from June 21 – June 27, average daily temperatures declined slightly before rising again. Average daily temperatures at the beginning of the season were about 5°C and by the end of the season, averages were around 15°C.

Depths fluctuated throughout the season, varying significantly between sites. The general trend was water depth decreased from the beginning of the season until a precipitation event around June 18 when depths increased (Figure 13). Following this event, water depth decreased through the end of the sampling season. The lower mainstem Fish River was tidally influenced at intermittent times.

Discussion

The most important objectives from 2009, the first full year of the study, were the estimates of smolt population abundance for the Niukluk and Fish rivers. These estimates were lower than modeled estimates, based on watershed size and/or parent spawner abundance, given published values. The explanations for this cannot be known with only one year of data collection; however, the study is designed to collect a second year of data, and a thorough discussion of the likely explanations, in advance, can help tailor the study in 2010 to address the most likely causes of the low numbers observed in 2009. We have included this discussion below, with the caveat that no firm conclusions about how the system works can be drawn from only one year of data.

Population estimates

The smolt population estimates in 2009 were lower than expected given literature values of smolts per spawner or smolts per habitat unit, but appear to be fundamentally sound in terms of the mark-recapture analysis. Reasonable numbers of fish were marked, the recapture rates were high enough to generate a narrow confidence interval, and we appeared to have captured the entire run (based on run timing graphs). We did not detect any size selectivity differences between mark and recapture sites, and were able to stratify by time period for both estimates. Mortality also did not seem to affect the estimates: there was little immediate mortality from the subsample of smolts held for 24 hrs on the Niukluk River, and travel time downstream was consistent enough with the literature (e.g., Quinn 2005) to suggest that sub lethal effects were minimal enough to not have measurably affected migration.

The smolt population studied in 2009 would have been produced by the escapement in 2006 (assuming a majority of age-2 smolts as indicated by prior years), and would have unusually low smolts per spawner relative to published literature. The 2006 escapement of coho salmon to the system was high, with an estimated 11,169 adults escaping to the Niukluk River. An expansion of the escapement to the entire watershed (using a 0.35:0.65 ratio of Niukluk River to the remaining drainage) would result in 31,911 adults returning back to the Fish River. Based on the confidence intervals for the smolt population estimates, these escapements would have produced 4.6 to 5.5 smolts per spawner for the entire Fish River, and 2.4 to 3.8 smolts per spawner for the Niukluk River portion. These numbers would be increased by any smolts that emigrated in 2008 or 2010, but would still be well below the literature values reported for coho salmon (see reviews by Shaul and Tydingco 2006; Shaul et al. 2008). Roughly, the Fish River estimate was 10% of the average estimated for 14 populations from Oregon to central British Columbia (using data from Bradford et al. 2000).

Similarly, the smolt production estimate was much lower than predicted using smolts produced per km of available rearing habitat. As part of the original proposal in 2007, we had estimated an expected 365 km of rearing habitat available to juvenile coho salmon. At "average" levels of smolt production per km for our source dataset (Bocking and Peacock 2005), this would have yielded between 316,000 and 682,000 coho salmon smolts (using 95% confidence intervals). The population estimate in 2009 reflects only 5% to 10% of the modeled estimates.

The result is that in 2009 we had population estimates that appeared accurate based on sample size, run timing, and mark-recapture diagnostics, but result in low smolt production values when compared to two different metrics from the literature (smolts per spawner and smolts per km of rearing habitat). From this, we can conclude that either (1) our 2009 smolt abundance estimates were incorrect, and by an order of magnitude on both parts of the river, (2) our 2009 smolt abundance estimates were accurate, but 2009 was an abnormally low year, or that 3) our estimates in 2009 were accurate, and reflect true levels of smolt production in the drainage. If this latter is true, it would be either because there are fewer km of rearing habitat being used, or because survival at some point from egg to smolt is unusually low. Each of these possibilities is discussed in more detail, below.

Explanation 1: The 2009 smolt population estimates were inaccurately low

It seems unlikely that the 2009 smolt abundance estimate(s) were inaccurate by the order of magnitude that would be observed if the true smolt abundance was within the range modeled from literature values of smolts per spawner or smolts per kilometer of rearing habitat. As described above, the mark-recapture diagnostics for both population estimates (the Niukluk and entire Fish rivers) were sound, and we sampled through what appeared to be both tails and the peak of the emigration timing curve in 2009. Furthermore, estimates from the nearby Nome River were also low in 2009, both in terms of relative abundance (50% of abundance in prior years) and smolts per spawner (4.2, which is similar to the Fish River in 2009; Unpublished data from LGL Alaska).

The estimates of smolt abundance in 2009 are also plausible given the known spawner escapements since 2001 and the range of marine survivals reported for coho salmon. For the past nine years, the mean coho salmon escapement past the Niukluk River tower was 5,804 adults, and the median was 3,498 adults. Our estimated range of smolts on the Niukluk River in 2009 will produce the median observed adult production in 2010 if the marine survival is 8.1% to 12.9%, which is within the recent historical range observed for the Nome River (Williams et al. 2009). The survival will need to be somewhat higher (13.5% to 21.5%) to achieve the historical mean adult escapement in 2010, but still within the upper end of the literature range (Shaul et al. 2008). The smolt population estimate for the entire Fish River matches up even better with historic adult returns to the watershed. Todd and Balland's (*in press*) estimate that the Niukluk River receives 35% of the total adult coho salmon run which would translate to a total Fish River run with a mean of 16,582 and a median of 9,994 returning annually since 2001. Our estimated smolt abundance in the entire Fish River watershed (95% CI: 145,897 – 174,803 smolts) would have had to survive at 5.7% to 6.9% to achieve the median escapement in 2010 and 9.5% to 11.4% to achieve the mean in 2010. Both of these numbers are realistic given documented coho marine survivals elsewhere (Bradford 1995; Shaul et al. 2008; Williams et al. 2009).

One source of error in 2009 could have been smolts that were flushed out of the system undetected during pre-season flooding. Water levels in 2009 were unusually high in the Fish River watershed; in late May and early June, the water was above the riverbanks and precluded any fish sampling. Water temperatures were generally two degrees or less during this time, which is below the temperatures at which we see smolts emigrate from the Nome River (Williams et al. 2009), so we consider it unlikely that smolts migrated from the Fish River during this time. The CPUE graphs support this, showing well-defined tails on both sides of our run curves, and smolts in the whole system in 2009 also migrated at approximately the same time as smolts monitored concurrently in the Nome River nearby (Figure 14). It is, however, still a possibility that we could have missed fish during this pre-season flood if a discrete pulse was flushed out.

Explanation 2: The true abundance of smolts in 2009 was unusually low

As noted earlier, smolt abundance on the Nome River was low relative to prior years, by approximately 50% (LGL Alaska, unpublished data). Smolts per spawner from the Nome River were also lower in 2009 (4.2) than in any of the four other documented years, and were similar (4.2) to the range estimated for the Fish River in 2009 (4.6 to 5.5). Smolts per spawner on the Nome River have been within ranges reported in the literature in prior years, suggesting that the low levels estimated in 2009 are unlikely to be a reflection of sampling error. It is worth noting that these unusually low smolt per spawner estimates came from unusually high adult escapements in each system (approximately twice the long-term average in each system).

There are no prior data showing how smolt production in the Nome and Fish drainages covary, but both systems received unusually high escapements in 2006, and presumably were subject to similar climatic systems since. If the Nome River smolt production was suppressed due to density dependent effects from the 2006 escapement, such effects could also have occurred in the Fish River, where escapements were also high in 2006. Similarly, climatic effects that would have affected the entire Nome River would seem likely to have also acted on the Fish River.

If the Fish River smolt abundance in 2009 was at 50% of the capacity (similar to the Nome River in 2009), the marine survival scenario analysis discussed above would almost perfectly predict the historic escapements to the watershed for the past 10 years. It would still, however, result in average smolts per spawner and smolts per km of habitat that are on the low end of the literature.

Explanation 3: Fish River smolt production is low relative to other rivers

Even if 2009 was an unusually low year for smolt abundance in the Fish, Niukluk, and Nome rivers, smolt production in the Fish River watershed still seems low relative to published values. This could possibly be due to less available habitat than expected for a watershed of its size, or from unusually high mortality between egg deposition and smolt emigration. Each of these can be examined further in 2010, and are discussed briefly below.

Nemeth et al. (2004) examined distribution of juvenile coho salmon in two Norton Sound watersheds (the Nome and North rivers) to estimate rearing habitat use by stream size. Coho salmon were found rearing in all 3rd order tributaries, and in a portion of the 2nd order tributaries. During proposal development for this project, we estimated the Niukluk River to have 365 km of stream habitat that was 3rd-order or higher. Such an estimate was meant to be conservative (by excluding all 2nd-order tributaries), but still appears to have overestimated smolt production per km of stream. On a relatively large river like the Niukluk, it may be that even some 3rd order waters are not used if they are located in certain combinations of elevation and distance from the ocean, or if they sometimes have barriers to juvenile passage. If, for example, juvenile coho salmon only reared in half of the 3rd order streams, a model using average production levels per km (from the streams in the predictor dataset) would almost perfectly predict the smolt abundance observed in 2009 (LGL Alaska, unpublished data).

Coho salmon smolt production has an allometric relationship with watershed size; as watershed size increases, smolt production per km drops because when a species is found in a small watershed, it is presumably well-adapted to the conditions in that watershed and thus at least moderately productive throughout it. In a larger watershed, such conditions may only represent a small proportion of the watershed, and the overall production per watershed unit (such as per km or m^2) is usually lower. In the regional dataset used to generate preliminary smolts per km estimates (Bocking and Peacock 2005), data came from few rivers the size of the Niukluk River. Revised numbers should be estimated using only source data from large rivers, thus excluding the smaller rivers that may be more productive. An important part of the 2010 study can be to test predictions of summer juvenile rearing, using a basic distribution study that targets 2^{nd} and 3^{rd} order streams. The results of this can then be included in the report from 2010, along with a second year of empirical smolt abundance estimates.

An alternative explanation for the apparent low production of smolts in the Niukluk River is that smolts may use as much rearing habitat as predicted, but that smolt production per km in the Niukluk River may simply be lower than in other rivers, including the Nome River. This could be because of heavy overwinter mortality of eggs or fry due to the cold winters, or from heavy mortality during the summer feeding and migration period (as fry or smolts), as noted in the original proposal. We attempted to quantify downstream survival in 2009, but were unsuccessful. We believe that these estimates can still be made in 2010, adjusting the sites based on what we learned in 2009. To qualitatively address winter habitat constrictions, we will describe and map the amount of unfrozen surface in the winter of 2009/2010. In addition, we will monitor progress of winter habitat mapping via remote imagery that is being conducted by another project on the Nome River. If this remote image methodology works on the Nome River, we will examine the feasibility of using it in the Fish River watershed in the winter of 2010/2011.

In 2010, we will structure the field sampling to help address questions about rearing habitat distribution, and will run a new version of the model using more detailed habitat data and using a sensitivity analysis that assesses the results of various scenarios of habitat use and production per habitat unit.

Freshwater survival and travel time

Our initial attempt to estimate downriver survival in 2009 resulted in improbably low estimates that were likely caused by insufficient sample size and distance among sites. In theory, the only difference between fish migrating downstream from A to C and B to C would be the mortality between A and B. This number was estimated at 50% in 2009, an unrealistically low number over the 25 km traveled. We suspect that our statistics from A to C were accurate, but that the numbers from B to C were flawed by either inadequate mixing of marked and unmarked fish, or by inadequate time elapsed to account for fish recovering from marking-induced stress. Our concerns were supported by calculating a population estimate based on fish marked at B and released at C for diagnostic purposes only (results not shown). This estimate would have resulted in a watershed wide estimate of approximately 45,000 fish, an improbably low number and much lower than the 160,000 smolt estimate shown in Table 6. We did, however, learn enough about coho salmon run timing and capture locations in the drainage in 2009 to make adjustments in 2010 that will help achieve this objective of downstream survival estimates.

Survival during outmigration is a function of distance traveled. Downstream survival rates in the Fish River will be interesting because of the presence of northern pike. In systems without pike, Quinn (2005) cites 99.8% survival/km as an expected baseline for outmigrating smolts. In the Fish River, that would yield a survival of 95.2% from the Niukluk River confluence down to the nets at White Mountain. On the other hand, Rutz (1999) demonstrated heavy predation of emigrating coho salmon smolts in a river system with pike and higher predation on coho salmon than other fish species. The central question for us, then, is whether smolts migrating down the Fish River have a survival rate that most closely resemble the estimates suggested by Quinn (2005), or whether survival rates are significantly lower than expected due to heavy predation by pike as found by Rutz.

Marine survival

The marine survival portion of the study was successful in that it placed tags into a relatively large number of smolts (~5,000) emigrating from the Niukluk River, and because 24-hr tag retention and fish survival numbers were high. Based on tag releases and the average adult escapement to the Niukluk River, our crews will need to examine 417 adults next year (approximately 5% to 10% of the mean annual adult escapement) to achieve a marine survival estimate within 25% of the true population size with 95% certainty (Robson and Regier 1964). Based on our experience in the Nome River, this is a feasible number of adults to capture and inspect.

Additional notes on fish biology, community assemblage, and environmental conditions in 2009

Run timing and travel times of coho salmon smolts

Catches and run timing on the Niukluk River closely matched the results from the pilot study on the Niukluk River in 2008 (Figure 15), and were similar to dates observed in prior years on the Nome River (Williams et al. 2009). Combined with multiple years of results from the Nome River, it appears that Norton Sound coho salmon smolts emigrate to sea in mid-June, which is substantially later than smolts from more southern latitudes that experience earlier water warming and ice out (e.g., Weitkamp et al. 1995). The 2009 smolt migration from the Fish River was spread over a larger time period than observed in the Nome River, however; this may be because a larger river (such as the Fish River) has more within-drainage variability in the environmental conditions that control emigration timing, and/or have more subpopulations with inherent differences in run timing cues. The peak CPUE of coho smolts migrating from the Niukluk River on July 3, for example, may have accounted for the second CPUE increase in the lower river in early July, and was associated with the warmest water conditions in the Niukluk River (Figure 16).

Rates of travel by outmigrating smolts are known to vary greatly, and can depend on discharge, temperature, hours of darkness, and fish body size. The average km/day traveled by Fish River coho salmon smolts was within observed outmigration speeds in other river systems. Most other estimates, however, have come within dammed river systems (Sandercock 1991, Quinn 2005), and we are not aware of any other travel time estimates for juvenile coho salmon in Alaskan tributaries to the Bering Sea. In an undammed watershed in Southcentral Alaska, nearly 50% of marked coho salmon smolts from one population had migrated 15 km in two days, and that 50% of smolts from a second population had migrated 27 km in four days (B. Williams, LGL Alaska, unpublished data).

Size structure

Larger smolts often experience higher marine survival, and a population of fewer, larger smolts may thus produce as many adults as a larger population of smaller fish. Coho salmon at the more northern portions of their range tend to have longer stream lives (two winters in fresh water as opposed to one winter; Sandercock 1991), and often have higher marine survival than more southern populations (Welch et al. 2002), perhaps due to a larger body size sometimes resulting from the extra year spent in fresh water. There is, however, large variation in smolt body size among watersheds and among years within the same watershed (Weitkamp et al. 1995). Coho salmon smolts from the Fish River averaged 102.5 mm in 2009, which is within the range reported for age-2 coho salmon juveniles from the nearby Nome River from 2004 through 2008 (Williams et al. 2009). Our initial inference from this is that the marine survival of these smolts is likely to be within the range reported for the Nome River from 2005 through 2009, given that both populations are likely to overwinter in similar parts of the ocean.

Conclusion and Recommendations

Conclusions from 2009

The population size of smolts from the entire Fish River and the largest tributary appeared to have been effectively estimated in 2009. An initial comparison to historic adult returns (using theoretical marine survival rates) suggests that these smolt estimates are relatively accurate. During the same year, estimates on the Nome River were 50% below average; if the Fish River drainage was similarly low in 2009 due to environmental factors affecting both systems, then past years may have been higher than 2009.

The estimates from 2009 were substantially lower than what would have been predicted by preliminary estimates from a habitat-based model transferred from outside the region. Although accurate on the Nome River in prior years, the model appeared to either overestimate the quantity or quality of rearing habitat on the Niukluk River. Full application of the model will be made in 2010, with sensitivity analysis and ground truthing to determine the most likely way to adapt it to the Fish River. It also remains possible that the model is effective, but that the low smolt numbers observed in 2009 resulted from unusually high freshwater mortality. Smolt mortality while emigrating downstream through pike habitat will be estimated in 2010, with the study design to be guided by information acquired in 2009.

The initial step of the marine survival portion of the study went well in 2009, with the placement of coded wire tags into 5,000 smolts from the Niukluk River, or about 15% of the estimated population. Based on historic adult returns, we will need to examine 417 adult coho salmon returning to the Niukluk River in 2010 to effectively estimate the marine survival of smolts that emigrated in 2009.

Recommendations for 2010

Population estimates

1. For the Niukluk River population estimate, attempt to place the mark and recapture nets farther apart. In 2009, these sites were 0.8 to 1.1 km apart, which could have prevented full mixing of marked and unmarked fish.
2. For the upriver capture process, attempt to staff the sites over the same time period as in 2009, but with one more person and one more boat. This will allow the crew to split into two when needed, and place more gear in the water to increase the sample size of fish handled.
3. In the lower Fish River, staff the sites over the same time period, but increase the crew size by one to decrease crew fatigue and respond to gear changes as needed.

Freshwater survival estimates

1. Adjust the study design and analysis to allow fish marked at the upstream sites and then captured at both B and C to be identified separately from fish recaptured at only one of B or C. Model the effect of recapturing from 1 to 10 fish (or more) at both sites to determine how effective a limited number of such recaptures will be.
2. Increase the distance among sites B and C, and preferably also between C1 and C2.
3. Collect stomach samples from pike, as outlined in proposals.

Marine survival estimates

1. Reevaluate the usefulness of minnow trapping for increasing the sample size.
2. Design the adult sampling program to sample adults between the 15% to 85% dates of the historic run time.

Model selection

1. Filter existing coho production database for streams similar in size to the Fish and Niukluk rivers.
2. Quantify the lineal km of each stream segment by stream order, and calculate the watershed area upstream from each segment. From this, develop a refined model that is able to be adjusted based on results from a rearing habitat study.
3. During the summer of 2010, use minnow traps to test rearing habitat use of juvenile coho in 2^{nd} and 3^{rd}-order streams in both the Niukluk and Fish rivers.

Acknowledgements

The study was funded by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, via the Alaska Sustainable Salmon Fund (Project 45673), with contributions from the Norton Sound Economic Development Corporation. We thank the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative for proposal review, study design comments, and funding approval, and the Bering Sea Fisherman's Association (BSFA) and Alaska Department Fish and Game (ADF&G) for assistance with project administration. S. Kent, J. Menard, B. Scanlon, E. Volk (ADF&G) provided insight on previous salmon studies in the region. K. Keith, S. Larson, and D. Harrelson with Norton Sound Economic Development Corporation (NSEDC) assisted with planning, installation and in-season logistics. R. Sparks, A. Barr, S. Lincoln, R. Willoya, (NSEDC) and S. Crawford and J. Konsor, (LGL) contributed to field work. D. Robichaud (LGL) helped with in-stream survival estimates. M. Bourdon (LGL) created GIS maps for this report. We thank the community of White Mountain for overall project assistance and for willingness to provide important local knowledge and support.

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Table 1. Historical escapement based on expanded counts of adult salmon past the Niukluk River tower by the Alaska Department of Fish and Game. Data are from Kent et al. 2008 and J. Menard personal communication 2009.

Year	Dates of Operation	Coho salmon	Pink salmon	Chum salmon	Chinook salmon
1995	June 29 – Sept 12	4,713	17,088	86,332	123
1996	June 23 – Sept 12	12,781	1,154,922	80,178	243
1997	June 28 – Sept 9	3,994	10,468	57,305	259
1998	July 4 – Aug 9	*840	1,624,438	45,588	260
1999	July 4 – Sept 4	4,260	20,351	35,239	40
2000	July 4 – Aug 27	11,382	961,603	29,573	48
2001	July 10 – Sept 8	3,468	41,625	30,662	30
2002	June 25 – Sept 10	7,391	645,141	35,307	621
2003	June 25 – Sept 10	1,282	75,855	20,018	179
2004	June 25 – Sept 8	2,064	975,895	10,770	141
2005	June 28 – Sept 9	2,727	270,424	25,598	41
2006	June 28 – Sept 8	11,169	1,371,919	29,199	39
2007	July 1 – Sept 4	3,498	43,617	50,994	30
2008	July 1 – Sept 6	13,779	669,234	12,078	33
2009	July 1 – Sept 2	6,861	24,204	15,879	204
Average 1999 – 2009		6,171	79,346 (odd yr) 924,758 (even yr)	26,847	128

* In 1998, the Niukluk tower counts ended before the majority of the coho salmon run returned.

Table 2. Harvest of adult coho salmon in the Fish and Niukluk rivers combined. Data are from Scanlon 2009. Note that the escapement numbers are the tower counts from the Niukluk River and that some of the harvest took place above the tower.

Year	Recreational Harvest	Subistence Harvest	Total Harvest	Escapement
1999	1,365	1,234	2,599	4,260
2000	1,165	2,335	5,145	11,382
2001	969	880	1,879	3,468
2002	298	1,640	1,938	7,391
2003	216	309	525	1,282
2004	291	652	943	2,064
2005	400	686	1,086	2,727
Average	672	1,105	2,016	4,653

Table 3. Sampling sites in the Fish River drainage and their respective distance upstream. All distances are in kilometers.

Location	Mouth of the Fish River	Confluence of Niukluk and Fish rivers
Non-sampling landmarks		
White Mountain	13.5	–
Confluence of Niukluk and Fish rivers	37.5	–
Council	57.5	20
Lower Fish River sampling sites		
FR-C1	15.3	–
FR-C2	16.3	–
FR-RST	17.8	–
Upper Fish/Niukluk River sampling sites		
NK-A1A	41.8	4.3
NK-A1B	41.5	4
NK-A2	40.7	3.2
FR-A3*	40.1	2.6

* FR-A3 is upstream of the Niukluk/Fish River confluence, but is in the Fish River, not the Niukluk River.

Table 4. Dates and locations of sampling sites in the Fish River drainage, 2009. GPS coordinates are in WGS84. No sites were sampled the morning of July 4, 2009.

Location	Gear Type	Code	Dates of Operation	Latitude	Longitude	Number of days Sampled	Number of days Available
Upper Fish/Niukluk rivers							
	Fyke Net						
		NK-A1A	June 11 – July 28	N64° 49.124'	W163° 28.953'	27	28
		NK-A1B	June 14 – July 8	N64° 49.360'	W163° 28.388'	25	25
		NK-A2	June 9 – July 8	N64° 49.377'	W163° 28.153'	29	30
		FR-A3	June 9 – 12	N64° 48.204'	W163° 25.594'	29	30
		FR-A3	June 12 – July 8	N64° 48.177'	W163° 24.067'		
	Minnow Trap						
		NK-M1	June 25 – 29, July 2 – 3	N64° 49.165'	W163° 27.101'		
		NK-M2	June 25 – 26, 28, June 29, July 1 – 3	N64° 49.165'	W163° 27.103'		
		NK-M3	June 25 – 30, July 2 – 3	N64° 49.162'	W163° 27.102'		
		NK-M4	June 25 – 29, July 2 – 3	N64° 49.377'	W163° 28.153'		
		NK-M5	June 25 – 30, July 2 – 3	N64° 49.377'	W163° 28.153'		
Lower Fish River							
	Screw Trap						
		FR-RST	June 6 – 15	N64° 42.112'	W163° 26.677'	40	42
		FR-RST	June 15 – July 17	N64° 42.446'	W163° 26.978'		
	Fyke Net						
		FR-C1	June 13 – 18	N64° 41.171'	W163° 25.605'	33	35
		FR-C1	June 18 – July 11	N64° 41.271'	W163° 25.738'		
		FR-C1	July 11 – 17	N64° 41.275'	W163° 25.718'		
		FR-C2	June 19 – July 12	N64° 41.743'	W163° 26.315'	27	29
		FR-C2	July 12 – 17	N64° 41.727'	W163° 26.329'		
		FR-Test-1	June 8 – 13	N64° 42.627'	W163° 27.990'	6	6
	Minnow Traps						
		FR-M1	June 20 – 21	N64° 42.458'	W163° 26.829'		
		FR-M2	June 20 – 21	N64° 42.213'	W163° 27.534'		

Table 5 . Coho salmon marked releases and recaptures by time strata, adjusted for length, in the Niukluk River, 2009. Release strata were pooled into three groups: 1 – 2, 3, and 4 – 5. Recovery strata were pooled into four groups: 1 – 2, 3, 4, and 5. Shading indicates pooling of strata. Abundance was estimated for coho salmon from 83 – 165 mm.

Release strata	Dates	Total releases (*n1*)	Recovery strata 1	2	3	4	5	Total	Recapture % (*p1*)
1	June 12 – June 14	79	0	3				3	3.8
2	June 15 – June 21	900		31	4			35	3.9
3	June 22 – June 28	406			55	41		96	23.6
4	June 29 – July 5	1051				119	52	171	16.3
5	July 6 – July 8	82					18	18	22.0
	Total	2518	0	34	59	160	70	323	12.8
	Number examined (*n2*)		116	718	849	986	353		3,022
	Proportion with marks (*p2*)		0.0	4.7	6.9	16.2	19.8		10.7

Population estimate	SE	95% CI
34,902	4,048	26,967 – 42,837

Table 6. Coho salmon marked releases and recaptures by time strata, adjusted for length, in the Fish River, 2009. Release strata 1 – 5 were pooled together. Recovery strata were pooled into two groups: strata 1 – 3 and 4 – 6. Shading indicates pooling of strata. Abundance was estimated for coho salmon from 81 – 140 mm.

Release strata	Dates	Total releases (*n1*)	Recovery strata 1	2	3	4	5	6	Total	Recapture % (*p1*)
1	June 10 – June 14	359	0	3					3	0.8
2	June 15 – June 21	3503		32	126				158	4.5
3	June 22 – June 28	2930			179	25			204	7.0
4	June 29 – July 5	2166				30	12	4	46	2.1
5	July 6 – July 8	425					7	7	14	3.3
6	July 9 – July 17	0						0	0	0
	Total	9383	0	35	305	55	19	11	425	4.5
	Number examined (*n2*)		163	1,386	4,487	858	91	278		7,263
	Proportion with marks (*p2*)		0	2.5	6.8	6.4	20.9	4.0		5.9

Population estimate	SE	5% CI
160,350	7,374	74,803

Table 7 . Coded wire tagging survival and tag retention for the Niukluk River, 2009. When tagged fish were not held overnight, the viable tagged numbers are calculated using the total retention for the season.

Date	# Tagged	# Held Overnight	Overnight Mortality	Adjusted Survival	# Retained Tags	Tag Retention	Viable Tagged
11-Jun	38	30	0	30	30	1.00	38
12-Jun	40	14	1	13	12	0.86	34
13-Jun	38	16	0	16	15	0.94	36
14-Jun	116	80	0	80	70	0.88	102
15-Jun	317	82	0	82	81	0.99	313
16-Jun	206	138	0	138	131	0.95	196
17-Jun	271	12	0	12	12	1.00	271
18-Jun	223						219
19-Jun	259	78	0	78	78	1.00	259
20-Jun	107	43	1	42	43	1.00	107
21-Jun	202	47	0	47	47	1.00	202
22-Jun	237	29	0	29	29	1.00	237
23-Jun	187	123	0	123	123	1.00	187
24-Jun	130	84	0	84	84	1.00	130
25-Jun	144	106	0	106	106	1.00	144
26-Jun	162	144	0	144	144	1.00	162
27-Jun	120	54	0	54	54	1.00	120
28-Jun	221	10	0	10	10	1.00	221
29-Jun	77						76
30-Jun	96						94
1-Jul	290	1	0	1	1	1.00	290
2-Jul	402	174	0	174	174	1.00	402
3-Jul	464						455
4-Jul	0						0
5-Jul	291	147	0	147	144	0.98	284
6-Jul	112	57	0	57	57	1.00	112
7-Jul	185	101	7	94	101	1.00	185
8-Jul	73						72
Total	5008	1570	9	1561	1546	0.98	4947

Table 8. Coded wire tag recapture sample sizes of adults returning to the Niukluk River in 2010. 4,947 coho salmon smolts were estimated to have retained their tags. This number of marked fish is shaded and shown with a range around it.

Smolt Population Estimate: 34,902

1 - Alpha	A	D	# of smolts marked	# of adults to examine
0.95	0.25	69.9	4,500	466
			4,750	438
			4,947	418
			5,008	412
			5,100	404

Table 9. Catch totals and proportions by location in the the Fish River drainage, 2009. All sites and gear are combined for each location.

	Upper River				Lower River					
	Niukluk sites[a]		Fish River		FR-RST		FR Fykes[b]			All Sites
Species	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Total	Percent
Alaska blackfish							1	0.0	1	0.0
Arctic grayling	617	6.5	17	0.1	195	2.6	422	1.3	1251	1.9
Arctic lamprey	1	0.0		0.0	47	0.6	45	0.1	93	0.1
Broad whitefish	9	0.1	2	0.0					11	0.0
Burbot							1	0.0	1	0.0
Chinook salmon (j)	19	0.2	11	0.1	22	0.3	129	0.4	181	0.3
Chum salmon (a)							1	0.0	1	0.0
Chum salmon (j)	703	7.4	7929	49.8	951	12.6	11137	33.2	20720	31.2
Coho salmon (j)	5749	60.7	4177	26.2	843	11.2	6503	19.4	17272	26.0
Dolly Varden	476	5.0	133	0.8	30	0.4	368	1.1	1007	1.5
Humpback whitefish							9	0.0	9	0.0
Lamprey spp. (a)	17	0.2	2	0.0			1	0.0	20	0.0
Lamprey spp. (j)	3	0.0	4	0.0	20	0.3	17	0.1	44	0.1
Ninespine stickleback	2	0.0	3	0.0	15	0.2	587	1.8	607	0.9
Northern pike			3	0.0	1	0.0	18	0.1	22	0.0
Pacific lamprey	3	0.0			1	0.0			4	0.0
Pink salmon (j)	1686	17.8	3596	22.6	4801	63.7	12022	35.9	22105	33.3
Rainbow smelt					22	0.3	506	1.5	528	0.8
Round whitefish			1	0.0	573	7.6	1495	4.5	2069	3.1
Sculpin spp.	185	2.0	27	0.2	9	0.1	209	0.6	430	0.6
Sockeye salmon (j)	3	0.0	15	0.1			8	0.0	26	0.0
Threespine stickleback							14	0.0	14	0.0
Unidentified					2	0.0	2	0.0	4	0.0
Whitefish spp.							1	0.0	1	0.0
Total	9473		15920		7532		33496		66421	

[a]Niukluk sites include NK-A1A, NK-A1B, and NK-A2, but not minnow traps
[b]Lower Fish River fyke nets include FR-C1, FR-C2, and FR-Test1

Table 10. Species richness, diversity, and evenness from all sampling sites in the Fish River drainage, June through July 2009. All sites in the Niukluk River are combined, as are all lower Fish River sites. Analyses are from Pielou (1968).

Location	S	H'	H'max	J'
Niukluk River	12	1.24	2.48	0.50
Upper Fish River	13	1.11	2.56	0.43
Lower Fish River	18	1.48	2.94	0.50
Total	19	1.49	2.94	0.51

Note: S = Species richness; H' = Shannon-Wiener index of diversity (-pi[lnpi]); H'max = ln(s); J' = Pielou's estimate of species evenness (H'/H'max).

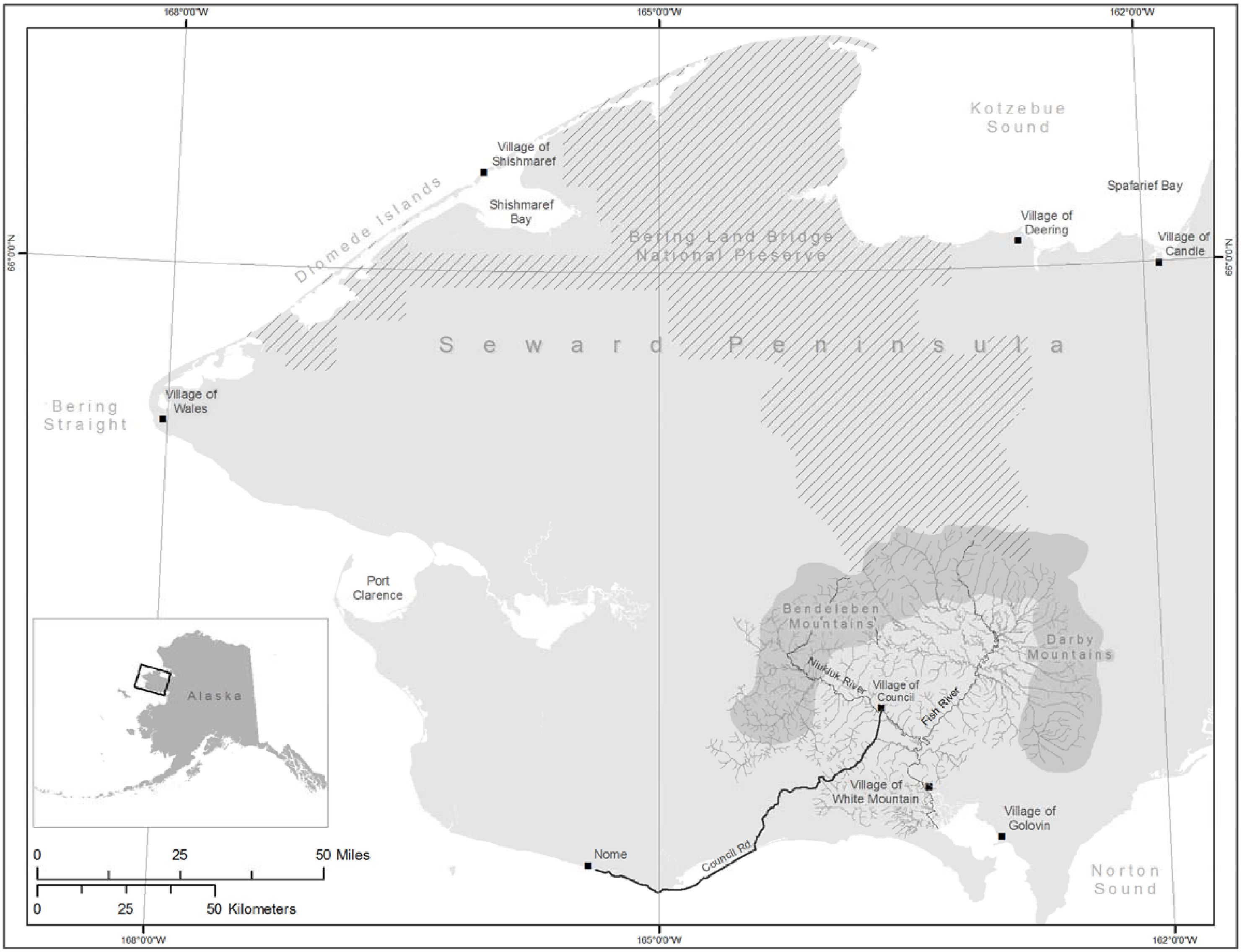

Figure 1. Study area showing proximal towns and detail of the Fish River watershed.

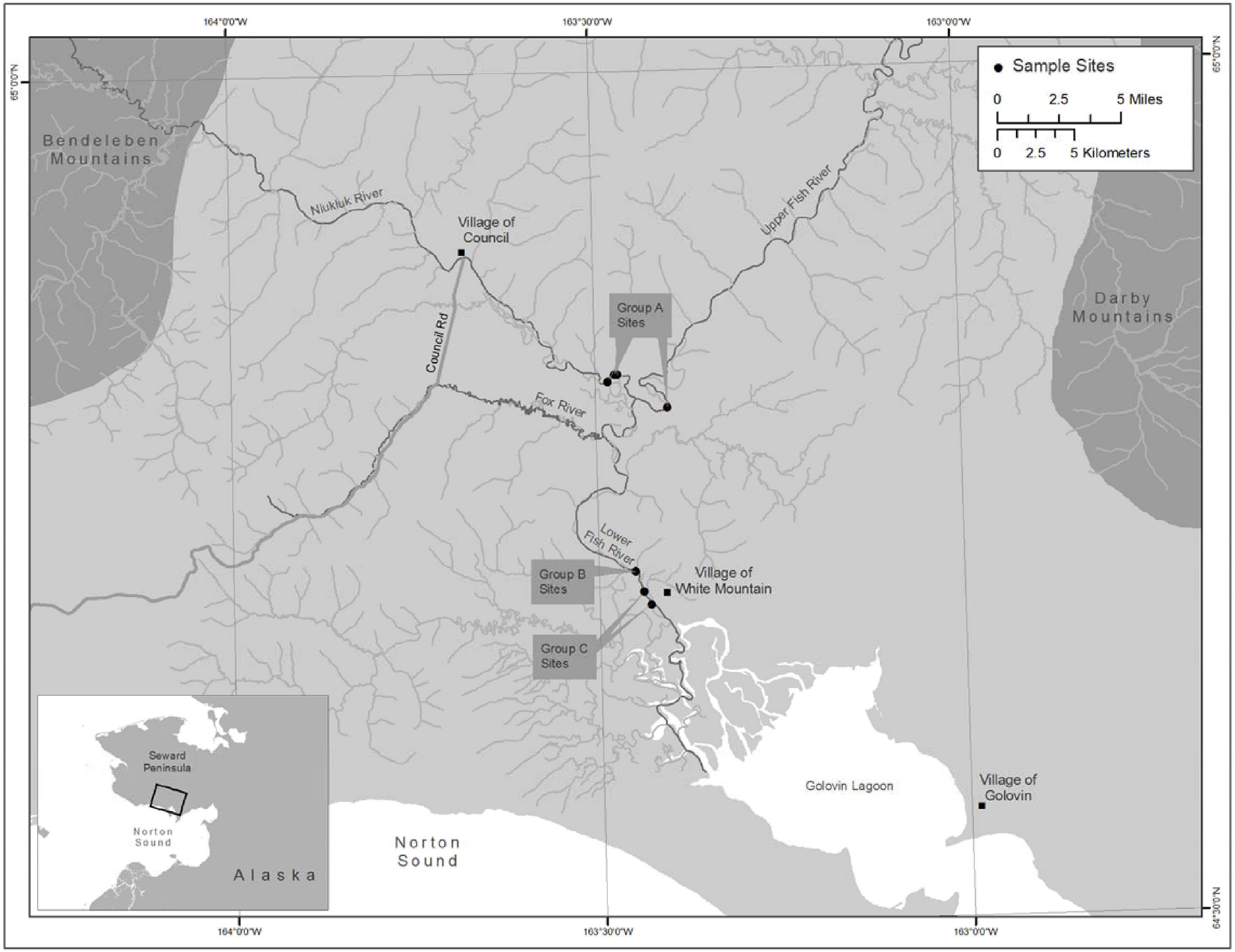

Figure 2. Sampling areas located in the Fish River drainage, 2009.

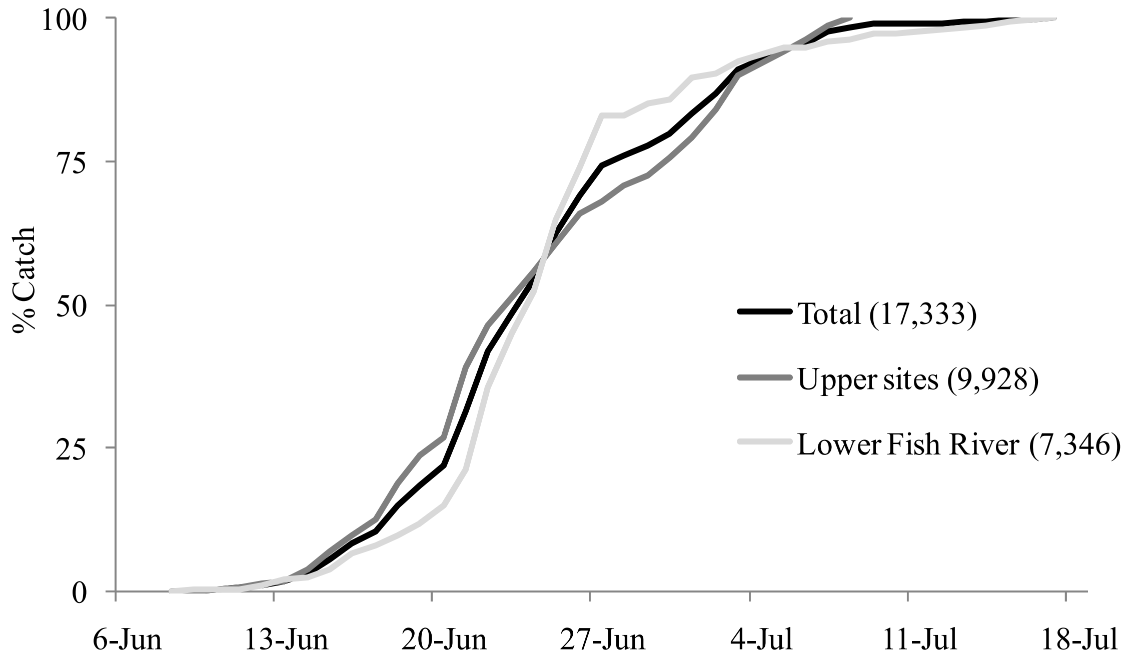

Figure 3. Cumulative numbers of coho salmon caught in the Fish River drainage in 2009. The midpoint of the coho salmon catch is June 23 for the upper sites. The midpoint for the lower sites and all sites combined is June 24, the vertical line represents the combined midpoint.

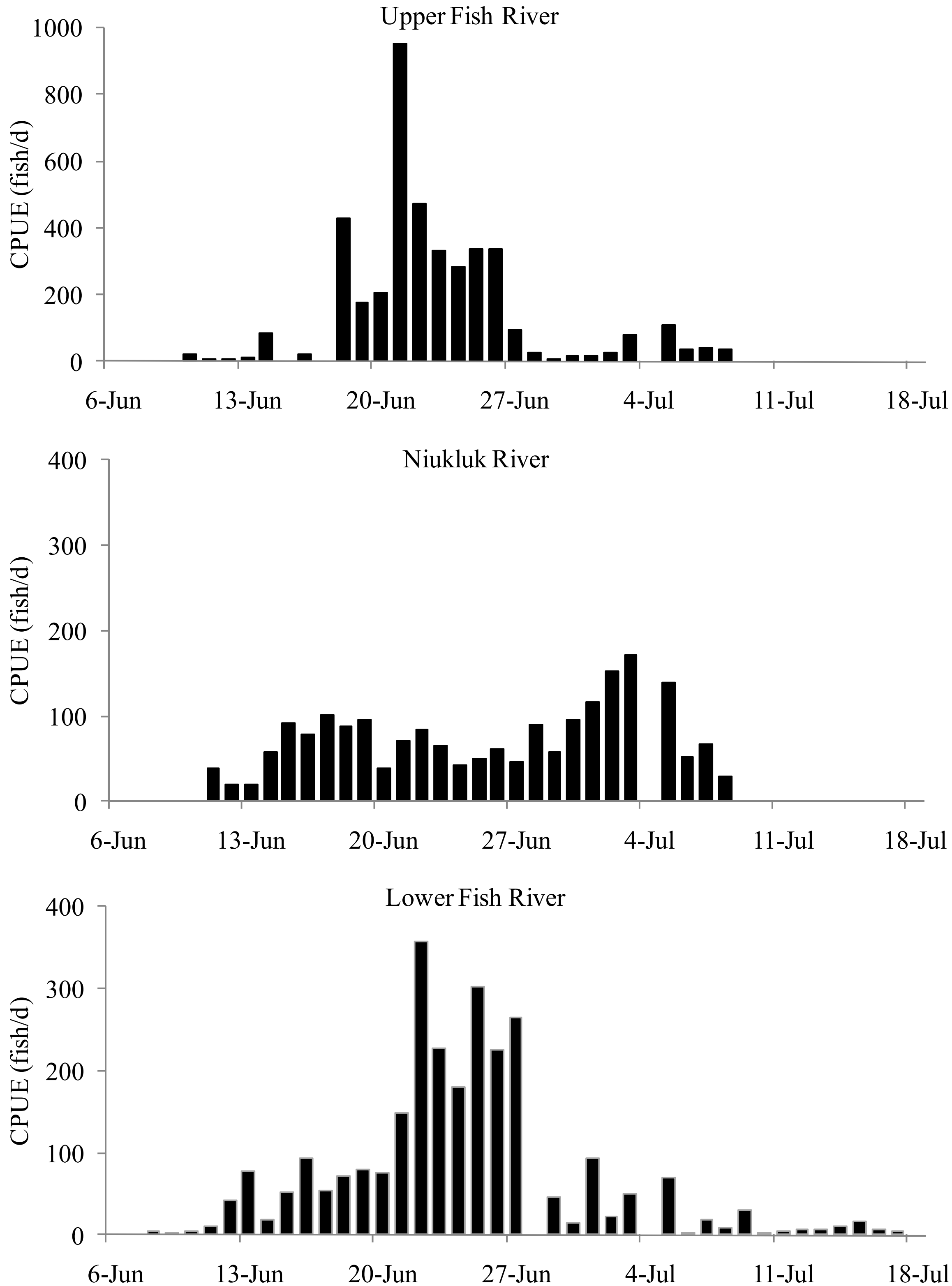

Figure 4. Juvenile coho salmon catch per unit effort (CPUE) in the Fish River drainage, 2009. Each chart includes all sites for that location.

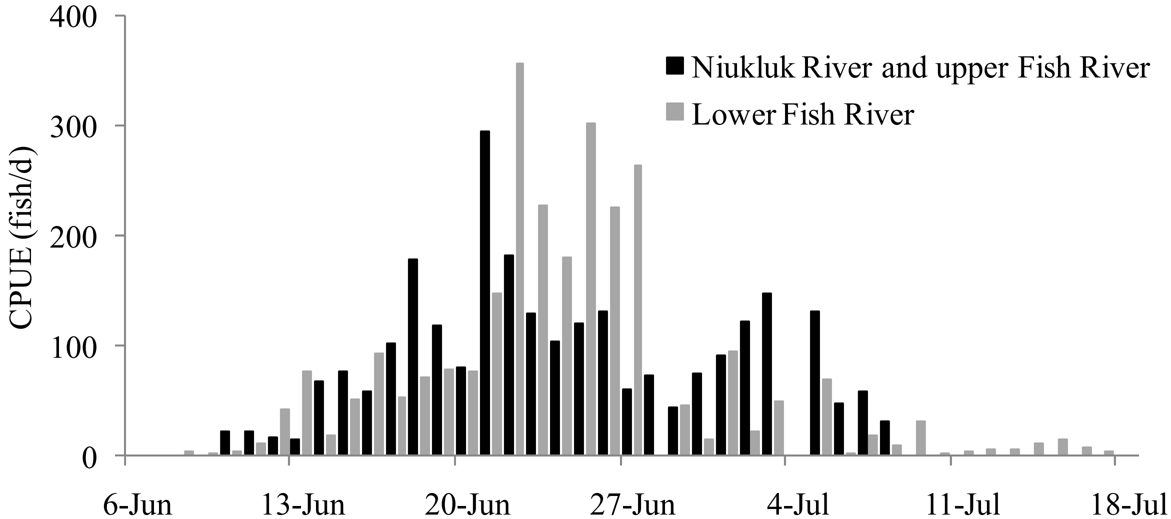

Figure 4 (continued). Juvenile coho salmon catch per unit effort (CPUE) in the Fish River drainage, 2009. All gear and sites are combined for each series.

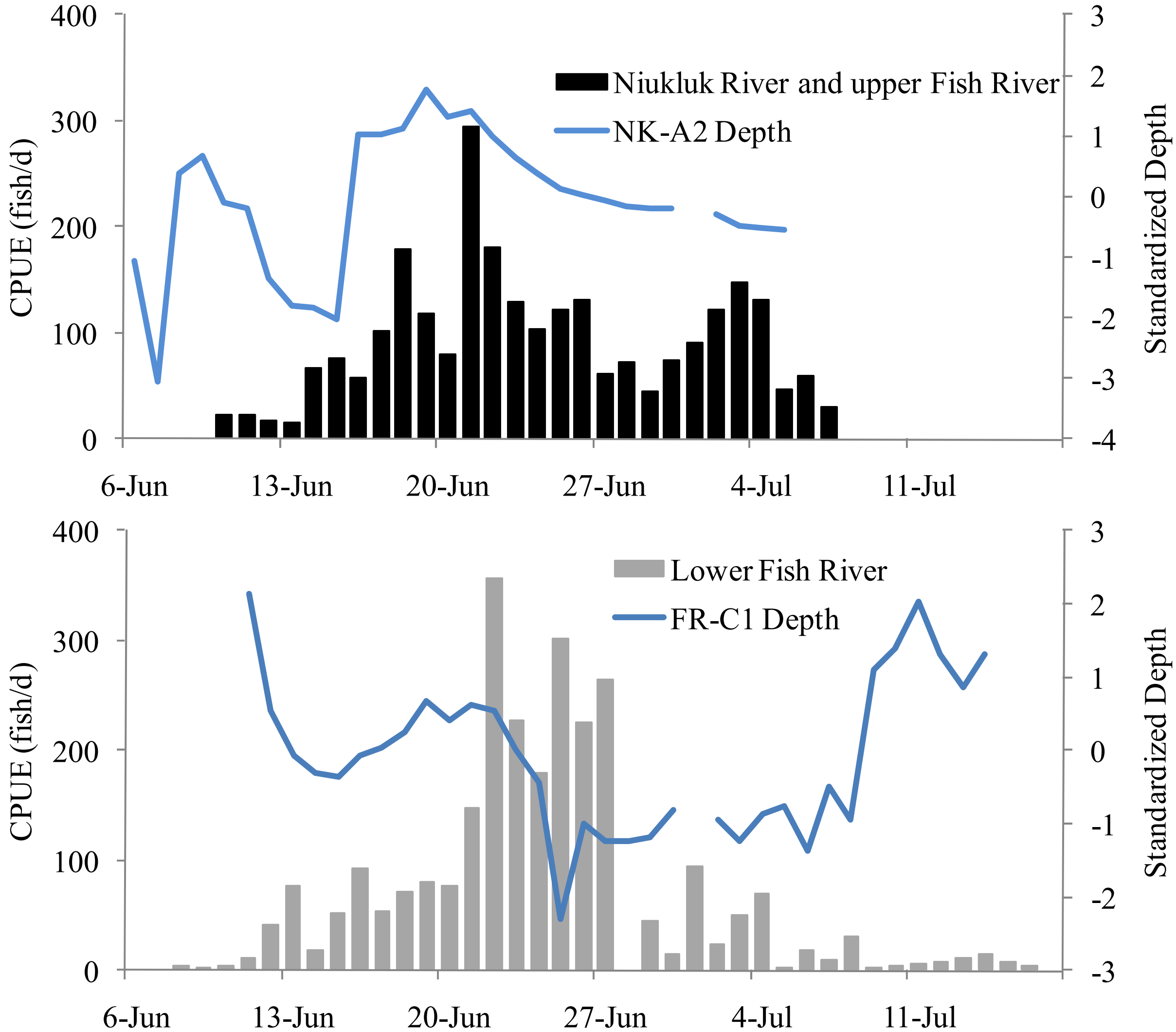

Figure 5. Juvenile coho salmon catch per unit effort (CPUE) and standardized depth in the Fish River drainage, 2009.

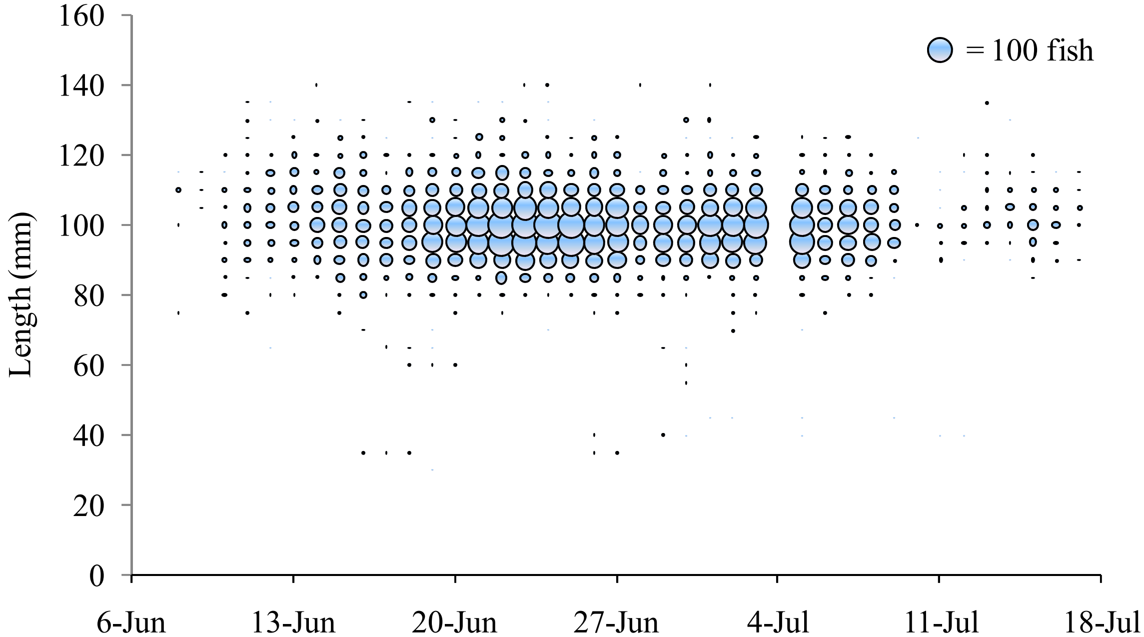

Figure 6. Juvenile coho salmon lengths by date in the Fish River drainage in 2009. All sites are combined. Lengths are only of randomly selected fish and include fish marked at upper sites and recaptured at lower sampling sites. Bubbles represent the number of fish sampled for each 5 mm length group.

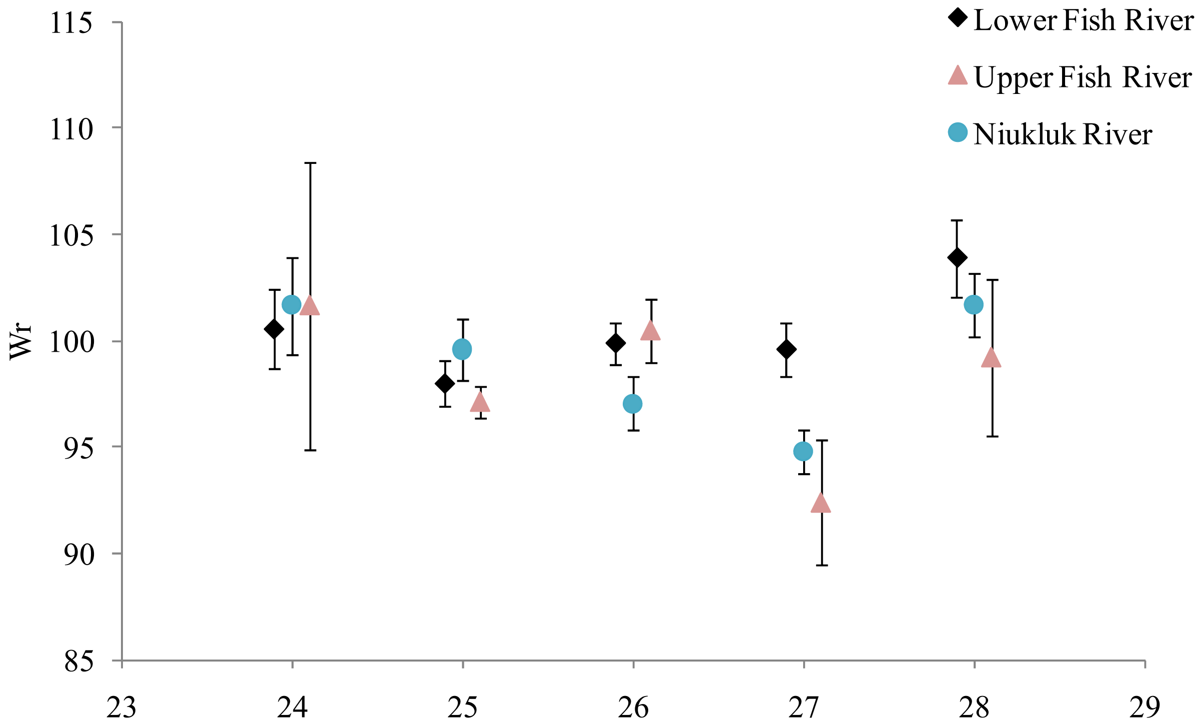

Figure 7. Juvenile coho salmon Fish River weekly mean relative weight (Wr), 2009. Weights are standardized against data from the Nome River 2004-2009. Error bars represent the standard error.

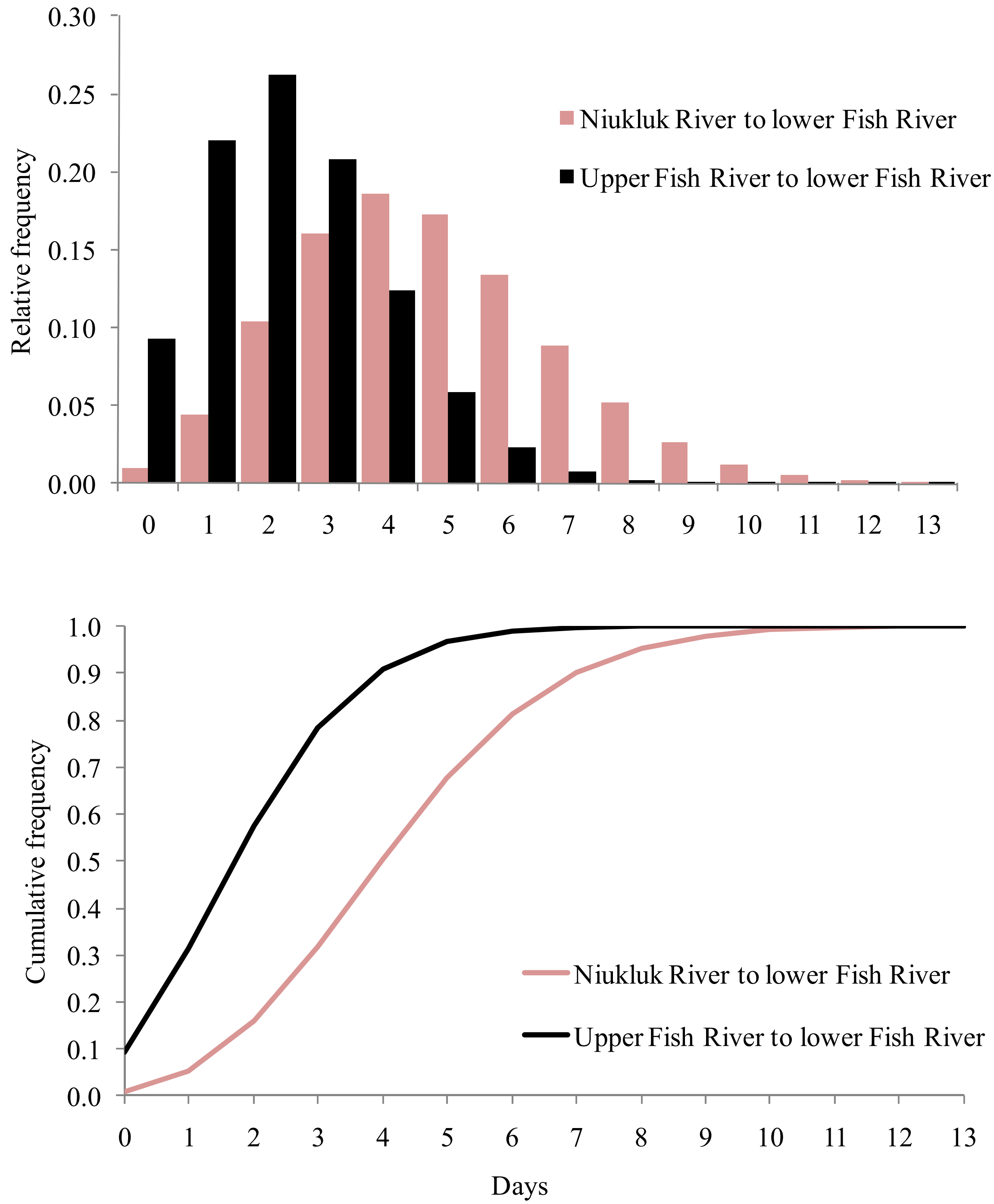

Figure 8. Modeled travel times of juvenile coho salmon between the upper and lower Fish River. Travel times are calculated using a constant travel model.

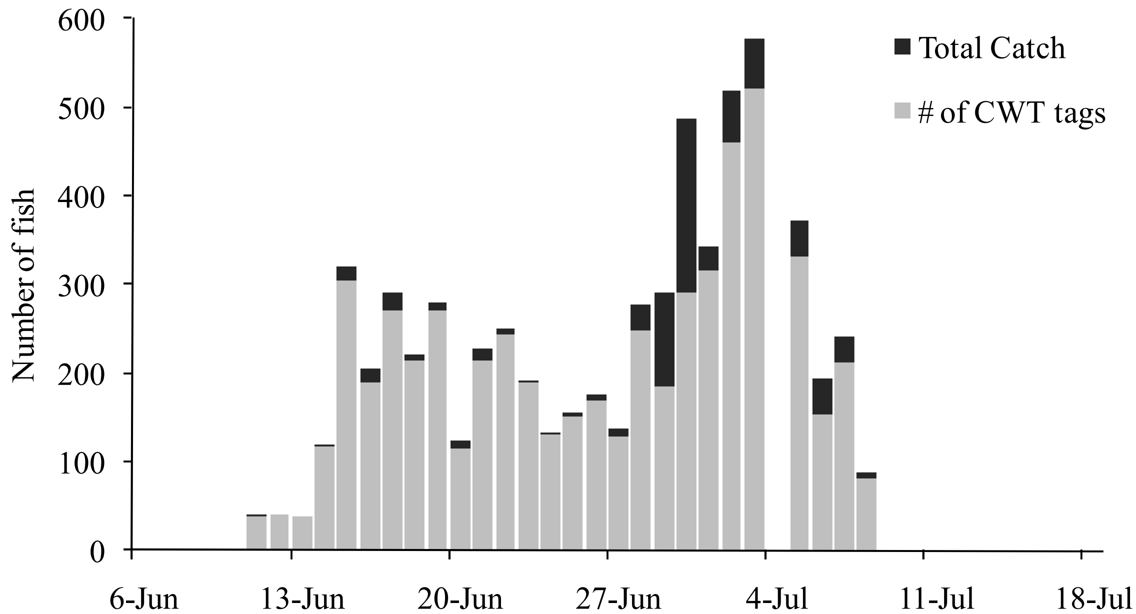

Figure 9. Total catch of coho salmon smolts in the Niukluk River with the number of coded wire tags (CWT) placed.

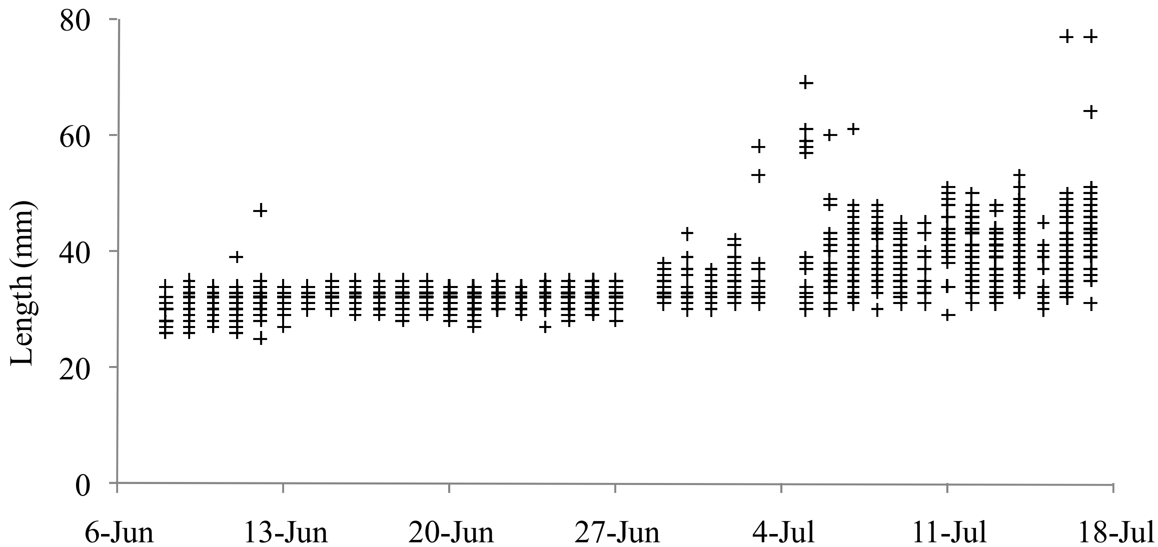

Figure 10. Pink salmon lengths in the lower Fish River, 2009. Lengths were not recorded at upper sampling locations.

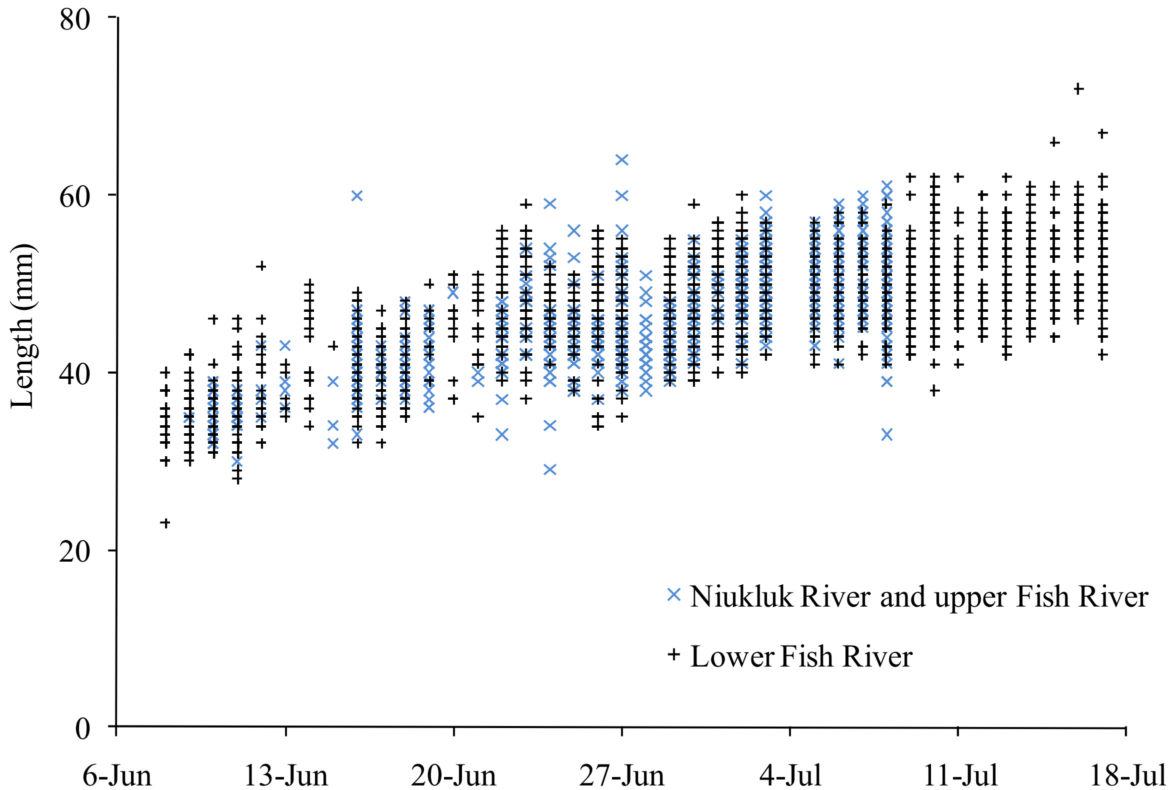

Figure 11. Chum salmon lengths by date in the Fish River drainage, 2009.

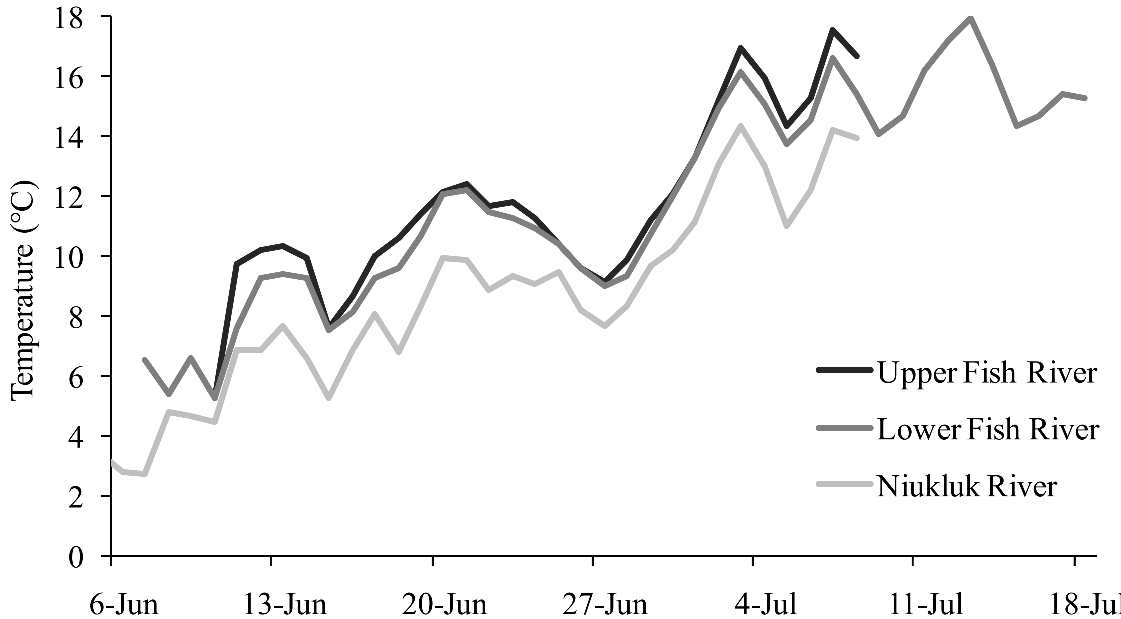

Figure 12. Mean daily temperatures (°C) in the Fish and Niukluk Rivers in 2009.

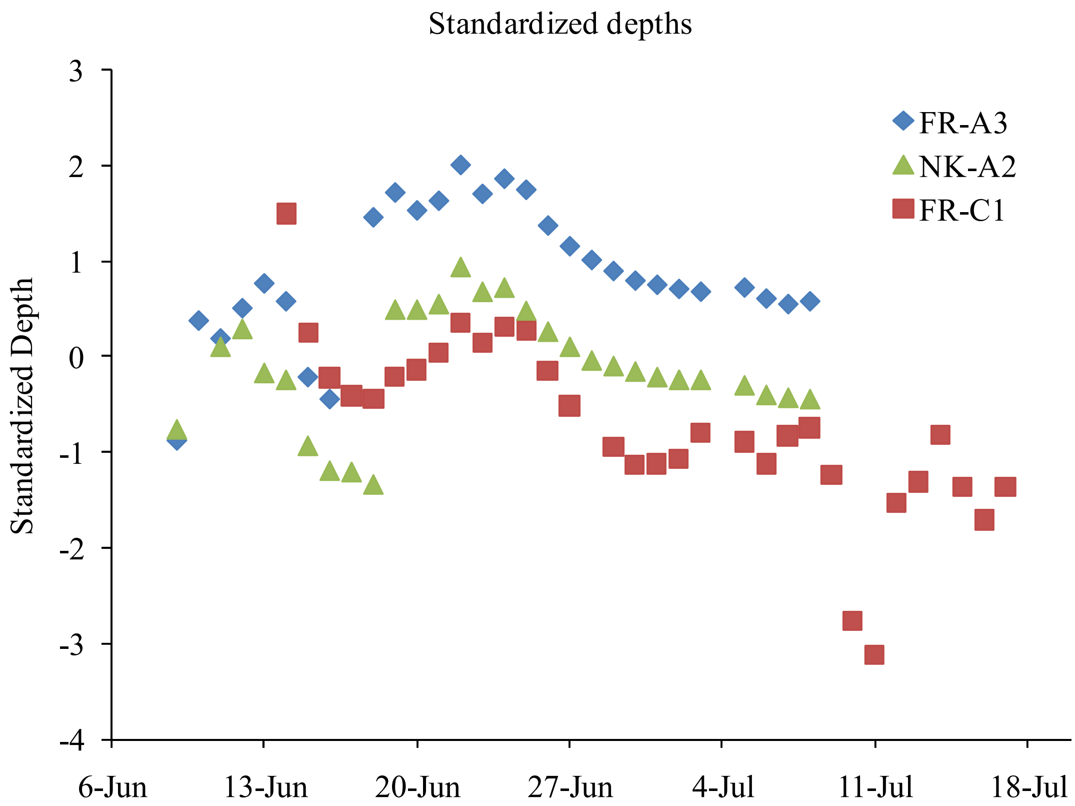

Figure 13. Standardized water depths (unitless) at three sampling sites in the Fish River drainage, 2009. Depth at FR-C1 may have been tidally influenced.

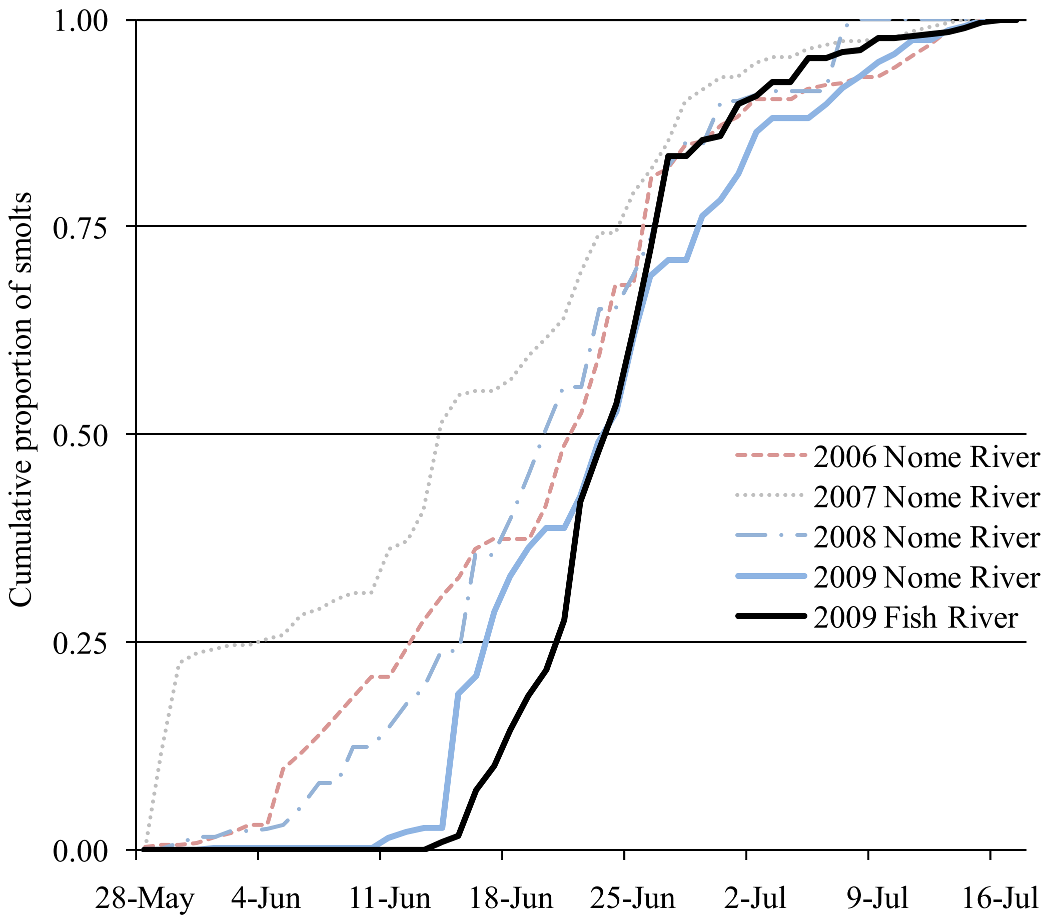

Figure 14. Cumulative catch of coho salmon smolts from the Nome River in 2006 – 2009, and from the Fish River in 2009. Fish River data are from the lower Fish River.

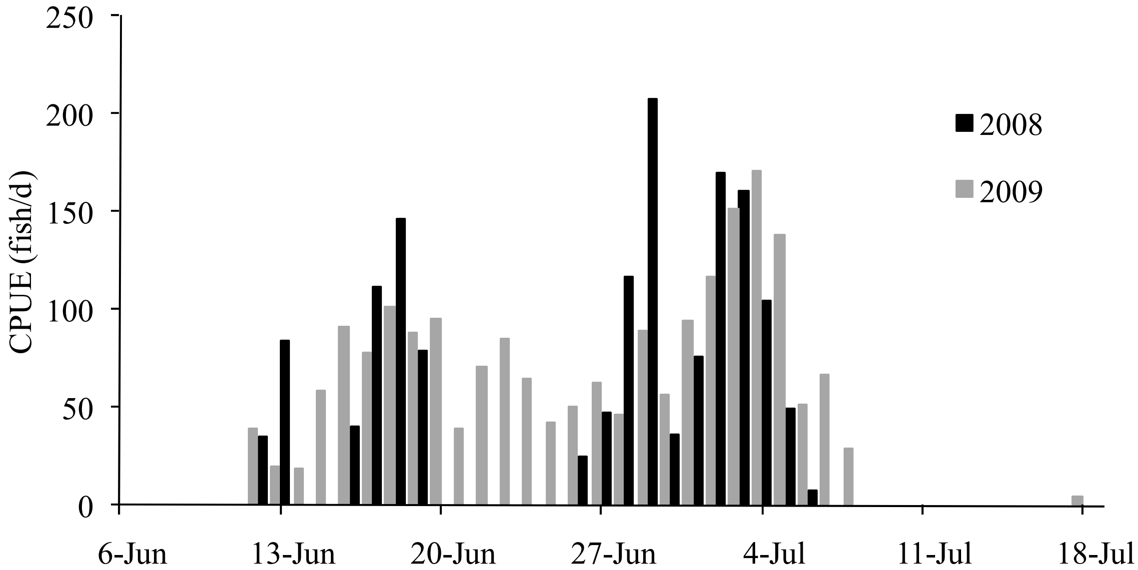

Figure 15. Coho salmon catch per unit effort (CPUE) compared between 2008 and 2009 sampling seasons. CPUE is expressed as number of fish caught per day of sampling. No sampling occurred from June 13 – 14 and 20 – 25, 2008.

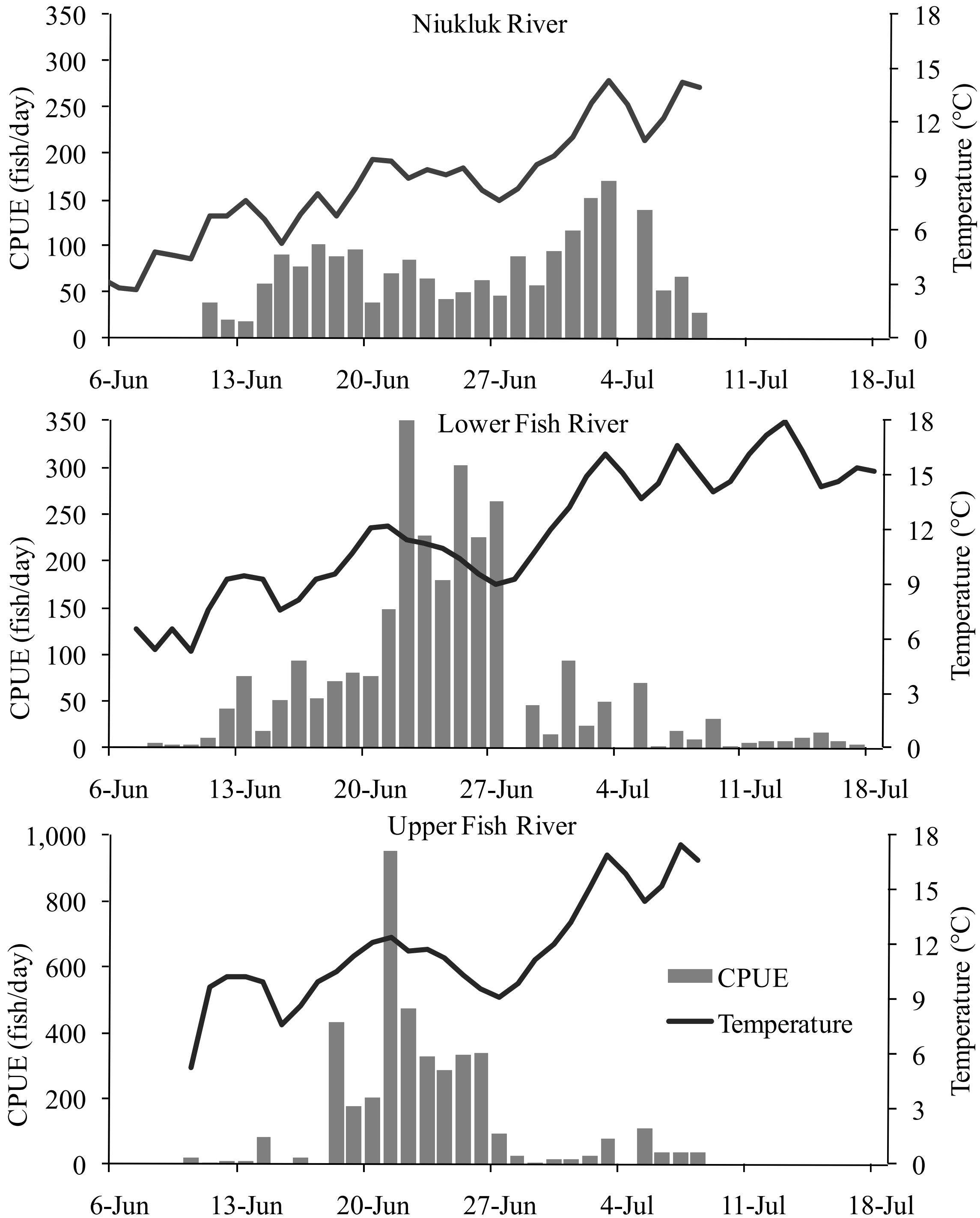

Figure 16. Juvenile coho salmon catch per unit effort (CPUE) with mean daily water temperatures (°C) in the Fish and Niukluk Rivers.

Photo 1. A fyke net operating during deep conditions at Site C. Wings are made of Vexar on one side and a beach seine on the other. Supporting rods are rebar.

Photo 2. A fyke net at Site C operating during normal conditions in July.

Photo 3. The rotary screw trap (RST) at Site B was placed in the thalweg to maximize catches.

Photo 4. The rotary screw trap (RST) at Site B operating close to shore to minimize interference with local boat traffic.

Photo 5. Crew members checking a fyke net for fish. A floating net pen is visible in the foreground.

Photo 6. A coho salmon smolt from the lower Fish River.

Photo 7. A crew member tags coho salmon smolts with coded wire tags (CWT) in front of a fyke net in the Niukluk River.

Appendix A. Catch totals by specific sampling site in the the lower Fish River, 2009.

Species	FR-C1	FR-C2	FR-RST	FR-TEST1	Minnow Trap A*	Minnow Trap B	Total Catch
Alaska blackfish	1						1
Arctic grayling	269	153	195				617
Arctic lamprey	18	27	47		2		94
Burbot	1						1
Chinook salmon (j)	85	44	22				151
Chum salmon (a)		1					1
Chum salmon (j)	9,299	1,666	951	172			12,088
Coho salmon (j)	3,425	2,954	843	124	17		7,363
Dolly Varden	221	109	30	38			398
Humpback whitefish	9						9
Lamprey spp. (a)	1						1
Lamprey spp. (j)	17		20				37
Ninespine stickleback	539	41	15	7		7	609
Northern pike	12	4	1	2			19
Pacific lamprey (a)			1				1
Pink salmon (j)	6,130	4,411	4,801	1,481			16,823
Rainbow smelt	4		22	502			528
Round whitefish	488	1,007	573				2,068
Sculpin spp.	148	59	9	2		1	219
Sockeye salmon (j)	5	3					8
Threespine stickleback	13	1					14
Unidentified	1	1	2				4
Whitefish spp.				1			1
Total	20,686	10,481	7,532	2,329	19	8	41,055

*Totals for Minnow Trap A include coho sampled with hook and line
(a) = adult, (j) = juvenile

Appendix B. Catch totals by specific sampling site in the the Niukluk River and upper Fish River, 2009.

Species	NK-A1A	NK-A1B	NK-A2	FR-A3	Minnow Traps A1	Minnow Traps A2	Total
Arctic grayling	57	242	318	17			634
Arctic lamprey			1				1
Broad whitefish		6	3	2			11
Chinook salmon (j)	2	2	15	11			30
Chum salmon (j)	102	601		7,929			8,632
Coho salmon (j)	2,014	675	3,062	4,177	2	40	9,970
Dolly Varden	160	71	245	133	1	1	611
Lamprey spp. (a)	12	1	4	2			19
Lamprey spp. (j)	2	1		4			7
Ninespine stickleback		1	1	3			5
Northern pike				3			3
Pacific lamprey	3						3
Pink salmon (j)	585	1,089	12	3,596			5,282
Round whitefish				1			1
Sculpin spp.	18	114	53	27	7	22	241
Sockeye salmon (j)		1	2	15			18
Total	2,955	2,804	3,716	15,920	10	63	25,468

Note: Minnow Traps-A1 also includes fish from traps NK-1 and NK-2.
Minnow Traps-A2 also includes fish from NK-3, NK-4 and NK-5.