U.S. Fish & Wildlife Service

Characteristics of Spawning Adult Steelhead in Crooked and Nikolai Creeks, Kenai Peninsula, Alaska, 2004-2009

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Soldotna, Alaska
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Characteristics of Spawning Adult Steelhead in Crooked and Nikolai Creeks, Kenai Peninsula, Alaska, 2004 - 2009

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Abstract

Adult steelhead *Oncorhynchus mykiss* were enumerated and sampled for age, sex, length, and genetic information in Crooked and Nikolai creeks during spring spawning migrations between 2004 and 2009. Fish weirs equipped with underwater video systems and fish traps were used to collect the information. Studies were initiated during 2004 in Crooked Creek and later included Nikolai Creek from 2005 to 2009. Escapement information was collected during all years and estimates of total escapement and run timing were obtained by analyzing information collected during years when at least half of the expected run duration was observed at both creeks (2006 – 2009). Mean estimated escapement from 2006-2009 was 708 steelhead for Crooked Creek and 560 steelhead for Nikolai Creek. Modeled run timing was similar for both creeks. Females comprised on average 58% of the run for Crooked Creek and 62% for Nikolai Creek. Mean lengths of male and female steelhead sampled from Nikolai Creek were larger than those sampled from Crooked Creek. Steelhead populations in each creek were comprised of up to 18 different life-history age patterns that included variations in smolt age, saltwater residence prior to sexual maturity, and number of spawning events. The predominant life history pattern found for Crooked Creek steelhead was three years of freshwater rearing followed by two years in the ocean prior to spawning, whereas the predominant life history pattern for Nikolai Creek steelhead was four years of freshwater rearing followed by three years in the ocean prior to spawning. More females than males were repeat spawners in both creeks. Genetic analyses of fin tissue samples indicated that steelhead populations in Crooked and Nikolai creeks were genetically distinct ($P<0.017$). Crooked Creek steelhead were genetically similar to those from Anchor River, a system located to the south of the Kasilof River that was the original source of broodstock used to enhancement the wild run to Crooked Creek.

Introduction

Crooked and Nikolai creeks were the only two streams in the Kasilof River watershed prior to 2008 known to support steelhead *Oncorhynchus mykiss* according to the Anadromous Waters Catalog (Johnson and Daigneault 2008). Since 2008, radio telemetry has been used to identify four additional spawning areas within the Kasilof River watershed: Indian, Shantatalik, and Coal creeks, and the mainstem Kasilof River (Gates 2009; Gates and Boersma 2010). Historically, Crooked Creek supported a small wild run of steelhead estimated at several hundred fish (Gamblin et al. 2004). The Alaska Department of Fish and Game (Department) enhanced this run beginning in the 1980's to provide additional angling opportunity. Enhancement efforts created a fishery unique from other steelhead fisheries on the Kenai Peninsula because it provided anglers an opportunity to harvest fish. Sport catches of steelhead in the Kasilof River and Crooked Creek peaked during the mid-1990s and averaged 5,836 fish between 1993 and 1995 (Appendix 1) (Mills 1994; Howe et al. 1995, 1996). During the same period, harvest of

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steelhead averaged 1,397 fish annually. Higher catches during this period were a direct result of the enhancement program. The enhancement program was terminated in 1993 after concerns were raised about straying of hatchery steelhead into the Kenai River. Since the termination of the enhancement program, catch has declined and has averaged 632 fish for the last 10 years between 1999 and 2008 (Appendix 1) (Gamblin et al. 2004; Jason Pawluk, Alaska Department of Fish and Game, personal communication). Anticipating a decline in the number of steelhead available to anglers, the Alaska Board of Fisheries restricted the fishery within Crooked Creek and the Kasilof River below the Sterling Highway Bridge to catch-and-release beginning in 1996. Since 1996, harvest has been restricted to waters upstream of the Sterling Highway Bridge and has averaged 18 fish annually from 1996 to 2008 based on Statewide Harvest Surveys (Appendix 1) (Howe et al. 2001 a-d; Walker et al. 2003; Jennings et al. 2004, 2006 a-b, 2007, 2009 a-b, 2010 a-b, Jason Pawluk, Alaska Department of Fish and Game, personal communication).

Current regulations allow steelhead fishing in Crooked Creek, the main stem Kasilof River, and Nikolai Creek. For Crooked Creek, fishing is allowed from August 1 through December 31, only unbaited, single hook, artificial lures may be used between September 15 and December 31, and no retention of rainbow trout or steelhead is allowed. For the Kasilof River, from the mouth to the Sterling Highway Bridge, fishing is allowed from September 1 through June 30 with one unbaited, single hook, artificial lure. Additionally, bait may be used with one single hook from May 16 through June 30. Like Crooked Creek, no retention of rainbow trout or steelhead is allowed in the Kasilof River below the Sterling Highway Bridge. For the Kasilof River above the Sterling Highway Bridge and Nikolai Creek, fishing is open year-round for rainbow trout and steelhead. The daily bag limit is 2 per day/2 in possession with only one fish exceeding 20 inches in length, and only 2 fish over 20 inches can be harvested annually.

Migrations of adult steelhead into freshwater are divided into two run components characterized by timing and physiology. The summer/fall run generally returns to freshwater between May and October and consists of steelhead with undeveloped gonads, while the winter run returns between November and April and consists of steelhead with developed gonads (Smith 1969; Barnhart 1986; Robards and Quinn 2002). Like other steelhead populations in Southcentral Alaska, steelhead returning to the Kasilof River watershed are considered fall-run fish, entering freshwater between mid-August and November and over-wintering before spawning in tributaries during May and June (Wallis and Balland 1982, 1983, and 1984; Larson and Balland 1989; Begich 1997). The presence of a winter run to the Kasilof River has not been documented but could exist. The emigration of spawned-out steelhead (kelts) from the Kasilof River watershed identified by Gates (2009) in 2008 and Gates and Boersma (2010) in 2009 follows similar patterns observed in the Ninilchik River, another steelhead stream located in Southcentral Alaska. The emigration of kelts passing downstream through a weir on the Ninilchik River occurs during spring and has been observed to start as early as 19 May, in 2000, and as late as 12 June, in 2001 (USGS, unpublished data). Kelt emigration from the Kasilof River watershed began as early as 12 May and as late as 23 May (Gates and Boersma 2010).

Steelhead from the Kasilof River watershed are thought to follow the same life history pattern described for other coastal wild steelhead populations in the Pacific Northwest. Steelhead in these populations sometimes survive to make two spawning migrations and up to five have been recorded (Bali 1959, Lindsay et al. 1991). Repeat spawners are predominately female due to higher post-spawning mortality among males (Shapovalov and Taft 1954; Chapman 1958; Withler 1966; Burgner et al. 1992). Higher mortality in males is attributed to their longer time on the spawning grounds and greater physical exertion due to the longer spawning periods, mating with multiple females, and combat with other males (Meigs and Pautzke 1941; Jones 1974). Wild steelhead primarily smolt at age 3 and return to spawn after 2 years in saltwater (Sanders 1985), whereas steelhead reared in hatcheries usually smolt after 1 year (Chapman 1958, Lindsay et al. 1991) and rarely spawn more than once. Although the steelhead run in Crooked Creek was once enhanced through hatchery operations, adults captured during the 2004-2006 spawning seasons exhibited life-history characteristics more similar to wild steelhead (Gates and Boersma 2009).

The overwintering distribution of steelhead in the Kasilof River watershed was poorly understood prior to 2008. Steelhead were thought to overwinter in the mainstem river, as indicated by harvest and catch information (Gamblin et al. 2004) and the observed spring spawning migration into Crooked Creek (Gates and Palmer 2006a, 2006b, 2008; Gates and Boersma 2009). The radio telemetry studies conducted by the U.S. Fish and Wildlife Service (Service) between 2007 and 2009 provided the first reliable documentation of steelhead overwintering areas in the Kasilof River watershed and showed that steelhead primarily overwintered in the mainstem Kasilof River upstream of the Sterling Highway Bridge, the Kasilof River near the outlet of Tustumena Lake, and Tustumena Lake (Gates 2009; Gates and Boersma 2010).

Investigations were initiated by the Service in Crooked Creek beginning in 2004. The primary objective during 2004 was to develop an underwater video system for enumerating steelhead. Since 2005, video systems and weirs have been operated in both Crooked and Nikolai creeks. Escapement estimates for Crooked Creek have ranged from 206 to 877 steelhead between 2004 and 2008 (Gates and Palmer 2006a, 2006b, and 2008; Gates and Boersma 2009). Information regarding the steelhead population in Nikolai Creek prior to 2005 was limited to visual observations made by (USGS) field technicians during the early 1990's (Carol Woody, U.S. Geological Survey, personal communication) and the presence of one steelhead captured in Tustumena Lake by Jones and Faurot (1991). Escapement estimates between 2005 and 2008 ranged from 84 to 588 fish in Nikolai Creek (Gates and Palmer 2006a, 2006b, 2008; Gates and Boersma 2009). Beginning in 2008, the Service's Office of Subsistence Management funded the Nikolai Creek weir through the Fisheries Resource Monitoring Program. This was in response to newly adopted Federal subsistence regulations beginning in 2007 and 2008 that expanded the methods and means, seasons, and harvest limits for salmon and other fish species in the Federal subsistence fisheries within Federal waters of the Kasilof River watershed.

Objectives for all years including 2009 were to: 1) estimate the abundance and run timing of adult steelhead entering Crooked and Nikolai creeks; 2) estimate the age, sex and length of adult steelhead entering Crooked and Nikolai creeks; and 3) determine whether the steelhead spawning in Crooked and Nikolai creeks are genetically distinct from one another and, if so, estimate the level of genetic differentiation. In addition to the previous three objectives, we tested the assumptions that steelhead from Crooked and Nikolai creeks display similar run timing, abundance, and other population characteristics (e.g. age, sex and length). This report summarizes findings from all years of data collection. Information pertaining to the run size, timing, and life-history of steelhead returning to Crooked and Nikolai creeks provides a better understanding of tributary spawners and assists managers in refining existing management strategies.

Study Area

The Kasilof River in Southcentral Alaska drains a watershed of 2,150 km^2, the second largest watershed on the Kenai National Wildlife Refuge (Refuge). The watershed consists of mountains, glaciers, forests, and the Kenai Peninsula's largest lake, Tustumena Lake. The Kasilof River is only 31 km long and drains Tustumena Lake, which has a surface area of 29,450 ha, a maximum depth of approximately 287 m, and a mean depth of 124 m. All tributary streams in the watershed that drain Refuge lands enter Tustumena Lake except Crooked Creek, which flows directly into the Kasilof River (Figure 1). Several species of salmon, trout, char, and whitefish use this watershed for spawning and rearing (Johnson and Daigneault 2008), including Chinook *O. tshawytscha*, coho *O. kisutch*, sockeye *O. nerka*, and pink salmon *O. gorbuscha*, rainbow trout/steelhead, Dolly Varden *Salvelinus malma*, lake trout *S. namaycush*, and round whitefish *Prosopium cylindraceum*.

Crooked Creek is a tannin-stained stream approximately 80 km long which flows into the Kasilof River at river-kilometer 11 (60° 19.20'N and 151° 16.55'W; NAD83). The headwaters of Crooked Creek are on the Refuge and the watershed drains approximately 75.6 km^2 (Moser 1998). Crooked Creek has a highly sinuous channel and substrates ranging from sand to cobble.

Nikolai Creek enters the south shore of Tustumena Lake approximately 8 km SE of the lake outlet (60° 11.43'N and 151° 0.36'W; NAD83). Its watershed is approximately 95 km^2 and falls within the Refuge boundary and a designated wilderness area (Moser 1998). Nikolai Creek has a relatively steep gradient, low sinuosity, and predominately cobble substrate.

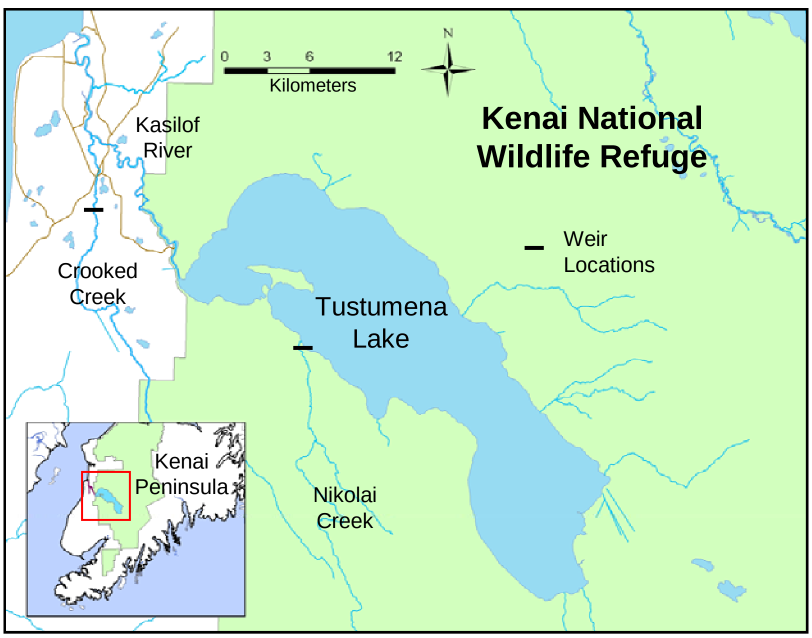

FIGURE 1. —Map of the Kasilof River watershed showing major hydrologic features and weir locations on Crooked and Nikolai creeks. Kenai National Wildlife Refuge lands are shaded green.

Methods

Weir and Video Design and Operations

The weir located at the Department's Crooked Creek Hatchery was installed to monitor the steelhead escapement in Crooked Creek. The hatchery weir is a permanent structure with a steel corrugated footer and bulkheads. Metal grates are placed onto the weir framework to divert fish migrating upstream into a hatchery raceway. An underwater video system was installed in the raceway to monitor fish passage. After passing the video system, fish exit the hatchery into Crooked Creek and continue their upstream migration. Fish moving downstream bypass the hatchery and pass over the weir unharmed.

The Nikolai Creek weir was located approximately 200 m upstream from the mouth of the creek and was constructed using a combination of floating resistance board panels (Tobin 1994) and flexible picket panels (Palmer 2003). Flexible picket panels were used in low velocity sections of the stream near each bank and were constructed from 2.5-cm inside-diameter polyvinyl chloride electrical conduit. Each flexible panel measured 3 m long by 1.5 m high with 1.9-cm spacing between pickets. Panels were held together by 3-mm stainless wire rope. Metal tripods were used to support the flexible picket panels. The floating portion of the weir was constructed using specifications outlined by Tobin (1994), with minor modifications to the panel width, picket spacing and resistance board material. The setup and design of the weir allowed upstream movement of fish through a counting chute. Downstream movement of fish occurred over a partially submerged floating weir panel. The Nikolai Creek weir was unmanned and outfitted with an underwater video and microwave system to monitor upstream fish passage.

Setup and design of the video systems have been described in earlier reports by Gates and Palmer (2006a, 2006b, 2008) and Gates and Boersma (2009). Each video system, consisting of a sealed camera box and fish passage chute, was typically attached to a live trap. Live traps facilitated biological sampling and were installed at the upstream end of the weir's fish passage panel. In the case of Crooked Creek, the video system was attached to the entrance of a hatchery raceway and the tail trough through which fish migrated was used as the live trap. The video boxes were constructed of 3.2-mm aluminum sheeting and were filled with filtered water. Safety glass was installed on the front of the video boxes to allow for a scratch-free, clear surface through which images were captured. Video chutes were constructed from aluminum angle and were enclosed in plywood isolating it from exterior light. Each video chute was modified in 2007 so that the backdrop could be adjusted laterally. This modification minimized the number of fish passing through the chute at one time and required fish to swim closer to the camera resulting in improved video images, especially during turbid water conditions. The backdrops were easily removed from the video chutes when dirty and replaced with a new one.

Video images from Nikolai Creek were broadcasted via a 2.4 GHz microwave transmitter to a digital video recorder (DVR) located at a private residence near the Sterling Highway. Microwave transmission of the video signal minimized power requirements at the remote site and allowed us to remotely monitor fish passage. The underwater camera, lights, and microwave transmitter at Nikolai Creek were powered by 12-V DC using three 80-W solar panels and one 54-W thermoelectric generator. The thermoelectric generator was only used during the 2009 season. In all other years, two solar panels wired in parallel supplied power to the underwater lights via four 400-Ah 6-V DC batteries wired in a series–parallel circuit to provide 12-V DC and adequate battery storage. The remaining solar panel maintained the charge on one 100-Ah 12-V DC battery which powered the underwater camera and microwave transmitter. The DVR for Nikolai Creek was operated with 110-V AC power at a private residence. All video equipment for Crooked Creek was located at the hatchery and powered with 110-V AC and 12-V DC for the underwater camera and lights. The video box and fish passage chute at each weir were artificially lit using a pair of 12-V DC underwater pond lights. Pond lights were equipped with 10- to 20-W bulbs; Nikolai Creek used 10-W bulbs to conserve power. Regardless of the bulb wattage, the lights produced quality images and provided a consistent source of lighting during day and night hours. All video images from each project were recorded on a removable 500 gigabyte hard drive at 20 frames-per-second using a computer-based DVR. Fish passage was recorded 24 hours per day seven days each week. Stored video files were usually reviewed daily. Each DVR was equipped with motion detection algorithms to minimize the amount of blank video footage and review time. Appendix 2 contains a list of video and microwave equipment used for this project.

Biological Sampling

Biological sampling was conducted to obtain information on the age, sex and length (ASL) composition and genetic variability of steelhead spawning populations in Crooked and Nikolai creeks. Since none of this information was available prior to this study, we attempted to sample as many steelhead as possible during each sampling event to account for scale regeneration, unusable genetic samples and future use in statistical analyses. To obtain representative samples of each spawning population, we scheduled sampling events so that sampling intensity matched steelhead abundance. A post-hoc power analysis (Cohen 1988) of male and female age and length samples from the 2004 pilot study at Crooked Creek (U.S. Fish and Wildlife Service, unpublished data) was conducted to estimate sample size requirements and confirm that appropriate sample sizes were taken at both creeks.

Age, sex and length. —Sex was determined by observing external characteristics during sampling efforts and video review. Fish with no assigned sex were marked as unknown and omitted from any analysis. Length measurements were taken as mid-eye to fork length (MEF) to the nearest 5 mm. Scales were removed from the preferred area using methods described by Mosher (1968) and Koo (1962). The preferred area is located on the left side of the fish, two scale rows above the lateral line and on a diagonal from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin. Four scales were taken from each steelhead, mounted on gummed cards, scanned digitally and analyzed by the Department. Scale analysis and reporting utilized methods described by Mosher (1969). Age determination denotes the number of winters spent in freshwater as a juvenile followed by the number of winters spent in saltwater as an adult prior to each spawning event. Spawning events are incorporated into the reporting methods described by Mosher (1969) and are denoted using the letter “S”. For example, a fish with an age determination of 3.2S1 spent three winters in freshwater, two winters in saltwater prior to its first spawning event and returned to saltwater for some period prior to its second spawning event. It is important to note that in this example this fish would have been sampled during its second spawning event prior to laying down a spawning check on the scale.

Genetic collection, preparation and genotyping. —Fin tissue samples were collected from adult steelhead in Nikolai Creek during 2008 (*N*=65) and 2009 (*N*=43), from Crooked Creek during 2006 (*N*=111) and 2008 (*N*=49), and the Anchor River during 2008 (*N* =95). Since brood stock from the Anchor River, whose mouth is approximately 82 km south of the mouth of the Kasilof River, was reportedly used to enhance the Crooked Creek run (Wallis and Balland 1983), we included Anchor River samples in the genetic analysis so that they could be compared to Crooked and Nikolai creek samples. All tissue samples were placed in 2 ml sample vials and preserved in 100% ethanol. Fifteen microsatellite loci were used to estimate genetic variation, including 13 loci standardized for use in *O. mykiss* (Stephenson et al. 2009). Total genomic DNA was extracted from fin tissue (~25mg) using proteinase K with the DNeasy™ DNA isolation kit (Qiagen Inc. Valencia, CA), quantified with fluorometry and diluted to a standard concentration. An MJResearch DNA Engine® thermal cycler was used to perform polymerase chain reactions (PCR) in 10 µl volumes; general conditions were: 2.5 mM $MgCl_2$, 1X PCR buffer (20 mM Tris-HCl pH 8.0, 50 mM KCl), 200 µM of each dNTP, 0.40µM fluorescently labeled forward primer, 0.40 µM unlabeled reverse primer, 0.008 units *Taq* polymerase, and 1 µl of DNA (30ng/µl). Standard thermal cycling conditions were: initial denaturation cycle of 94°C for 3 min, followed by 94°C for 1 min, 50-62°C for 1 min (locus-specific annealing temperature), 72°C for 1 min, with a final single cycle of 72°C for 10 min. One-half µl of PCR product was electrophoresed and visualized with the Applied Biosystems 3730 Genetic Analyzer utilizing a polymer denaturing capillary system. Microsatellite allele sizes were estimated and scored by the computer program GeneMapper® version 4.0. Applied Biosystems GeneScan™-600 LIZ® size standards, 20-600 bases, were loaded in all lanes as an internal lane standard. All scores were verified manually by two independent researchers, with discrepancies being resolved by replicating the analysis for the samples in question and repeating the double scoring process until scores matched. Unresolved scores were excluded from further analysis. Data for samples from at least one row in each 96-well sample plate were automatically replicated to confirm that proper plate orientation was maintained throughout genotyping efforts for the project.

Environmental

Water temperatures were recorded at each weir location using an Optic StowAway Temp logger (ONSET Computer Corporation®). Temperatures were recorded every 30 minutes and averaged for the day for reporting purposes. Temperature loggers were typically operated for the duration of each project but during some years temperature recordings extended beyond the weir operational period.

Data Analysis

Run timing and abundance. —The analysis and estimation of complete run timing and escapement were limited to years when at least half of the expected run duration was monitored at both creeks (2006 – 2009). In addition, dates with incomplete observations were omitted from run timing analysis. A three parameter sigmoidal nonlinear regression (Bates and Chambers 1992) was used to model run timing and produce 95% prediction intervals (PI) for both creeks using the non-linear least squares (nls) function of R version 2.10.1 (RDCT 2009). The model was defined as:

$$f_i = \frac{\beta_1}{1 + e - \left(\frac{x_i - \beta_2}{\beta_3}\right)},$$

where f_i is the cumulative proportion of passage at date x_i; β_1 is the peak value of f_i; β_2 is the date at median passage; and β_3 is the width of the curve transition. The proportion of passage predicted by the model was used to estimate passage for dates with either no or incomplete observations. These estimates were calculated as:

$$n = \left(f_i - f_{i+1}\right)\left(Obs\right),$$

where n is estimated passage; f_i is the cumulative proportion of passage at date x_i; f_{i+1} is the cumulative proportion of passage at date x_{i+1}; and *Obs* is the observed passage for the period of interest. Annual abundance estimates were then tested for differences in means between creeks using a two sample t-test for paired samples.

Age, sex, length. — The assumption that steelhead destined for Crooked and Nikolai creeks displayed equivalent demographic traits was tested using multiple statistical tests in R version

2.10.1 (RDCT 2009) in order to characterize and compare the ages, sexes, and lengths of steelhead sampled from each creek. An exact chi-square test using the "chi.test" function was used to individually test the homogeneity of male and female life history age classes, including freshwater age at smoltification, saltwater ages prior to the first spawning event, and spawning events within and among creeks. Given the relatively small sample size for each life history trait and the potential existence of life history aggregations within the run, an exact chi-square test with 10,000 replications was used to increase precision of the sample (Agresti 2002). Mean sex compositions including 95% confidence interval's (CI) were estimated using a single sample t-test (t.test).

Observations of sexes were omitted from the analysis during years when sex ratios were highly skewed because of late project start dates and incomplete counts during high water events that occurred early in the spawning migration (Crooked Creek: 2004 and 2005; Nikolai Creek: 2005 and 2009). For the remaining years, sex composition of each run was estimated either by combining sex information obtained from ASL samples and observations made during review of video images (Crooked Creek: 2006 and 2008 ; Nikolai Creek: 2008) or entirely from video images during years in which ASL samples were not collected (Crooked Creek: 2007 and 2009; Nikolai Creek: 2006 and 2007).

Lengths of male and female steelhead collected over the duration of both projects were also tested for homogeneity by sex among inter-annual samples from each creek using a Kruskal-Wallis one way analysis of variance on ranks (kruskal.test). Analogous samples were then pooled by sex at each creek. Because samples did not meet the underlying assumptions for parametric tests (i.e. normal distribution) a basic bootstrapped 95% CI with 10,000 replications was calculated for each of the pooled samples using the "boot.ci" function. Additional CIs obtained by bootstrapping were used to investigate the difference in means for sexes within creeks as well as like sexes among creeks.

Genetic diversity within and among populations. —Allelic richness and observed and expected heterozygosity were computed for all loci for each putative population. A Wilcoxon paired-sample test was used to assess if estimates of allelic richness and expected heterozygosity differed among populations over loci. Randomization tests for conformity to Hardy-Weinberg equilibrium were conducted for each locus, after pooling populations, and for each population, after pooling loci. Randomization tests for genotypic disequilibrium were conducted for all locus pairs in each population using FSTAT version 2.9.3 (Goudet 2001). A *G*-test of allele frequency homogeneity was used to test for genetic differentiation between pairs of populations and among inter-annual samples within locations (Crooked and Nikolai creeks). An estimate of the degree of genetic population structure based on the relative measure F_{ST} was computed over all populations and for each population pair according to Weir and Cockerham (1984). All loci were pooled for *G*-tests and to estimate F_{ST}.

Environmental. —The assumption that the average daily water temperatures collected from 2005 to 2009 between 26 April and 30 May at Crooked and Nikolai creeks were equal was tested using a paired t-test. A three parameter peaked Gauussian nonlinear regression (Bates and Chambers 1992) was used to estimate the proportion of total fish passage observed at categorized mean daily water temperatures in both Crooked (2004 - 2009) and Nikolai creeks (2005 – 2009) using the nls function of R version 2.10.1 (RDCT 2009). The model was defined as:

$$f_i = \beta_1 e^{\left[-.05\left(\frac{x_i - \beta_2}{\beta_3}\right)^2\right]},$$

where f_i is the proportion of passage at temperature x_i; β_1 is the peak value of f_i (amplitude); β_2 is the temperature at peak passage; and β_3 is the width of the curve at f_i=f_i peak/2. In addition, we used a one sample t-test to estimate a 95% CI for mean daily water temperatures recorded for the first observed fish at each weir. This analysis only included years when we were confident the video weirs were installed prior to the first fish passing each weir site (Crooked Creek *N*=4 years; Nikolai Creek *N*=3 years).

Results

Weir and Video Operations

Crooked Creek.—The installation of the weir and video system in Crooked Creek on 4 May 2004 was the latest start date among all years. After 2004, start dates varied between 21 and 29 April (Appendix 3). Start dates during 2004 and 2005 were most influenced by ice conditions in the creek and hatchery raceways. To ensure that the majority of the steelhead escapement was monitored in subsequent years, we began to install the weir and video system regardless of ice conditions beginning in 2006. We accomplished this by manually removing ice near the flood valve at the head of the hatchery several days in advance of our target start date. This allowed water to enter the raceways and facilitated rapid ice melt in the raceways and tail trough. Any remaining ice was chipped away during the installation period. The weir and video system were installed prior to substantial fish passage in four of the six years. Project end dates have also varied among years and were based on observed fish passage for all years except 2009, when operations ended prematurely because of scheduled maintenance to the hatchery.

Nikolai Creek.—The installation of the weir and video system in Nikolai Creek on 4 May 2005 was the latest start date among all years. After 2005, the weir and video system were installed on 25 April regardless of the environmental conditions (Appendix 4). Key components to the weir were left in place between seasons because of the prevalence of anchor and shore ice in the creek during the installation period. This allowed us to install the weir and video system in less than two days, and the project was operational prior to spring flooding in most years. Flooding occurred annually, was common during the peak of the spawning migration, and varied in magnitude among years. The weir was submerged on several occasions each year because of the high discharge and our inability to clean the weir during the early part of the season. Access by boat was restricted to the weir site due to the prevalence of lake ice during early May. Technical problems associated with the video equipment occurred infrequently and were quickly repaired. Fish counts were estimated for periods with either no or incomplete counts during years when at least half of the expected migratory period was monitored at both creeks (2006 – 2009; Appendix 4).

Escapement and Biological Information

Run timing and abundance.—Estimates of run timing and abundance were obtained for both Crooked and Nikolai creeks (Figure 2). Modeled run timing was similar for both creeks, and their 95% PIs overlapped (Figure 2). However, the progression of escapement at Crooked Creek was more normally distributed than that of Nikolai Creek. The estimated date when the first 10% of passage was reached is 2 May (95% PI, 29 April to 3 May) at Crooked Creek and 5 May

(95% PI, 1 May to 7 May) at Nikolai Creek. The estimated dates of median passage are 10 May (95% PI, ±1 day) at Crooked Creek and 12 May (95% PI, ±1 day) at Nikolai Creek. The estimated date of 90% passage is 18 May (95% PI, 16 May to 21 May) at Crooked Creek and 19 May (95% PI, 18 May to 23 May) at Nikolai Creek.

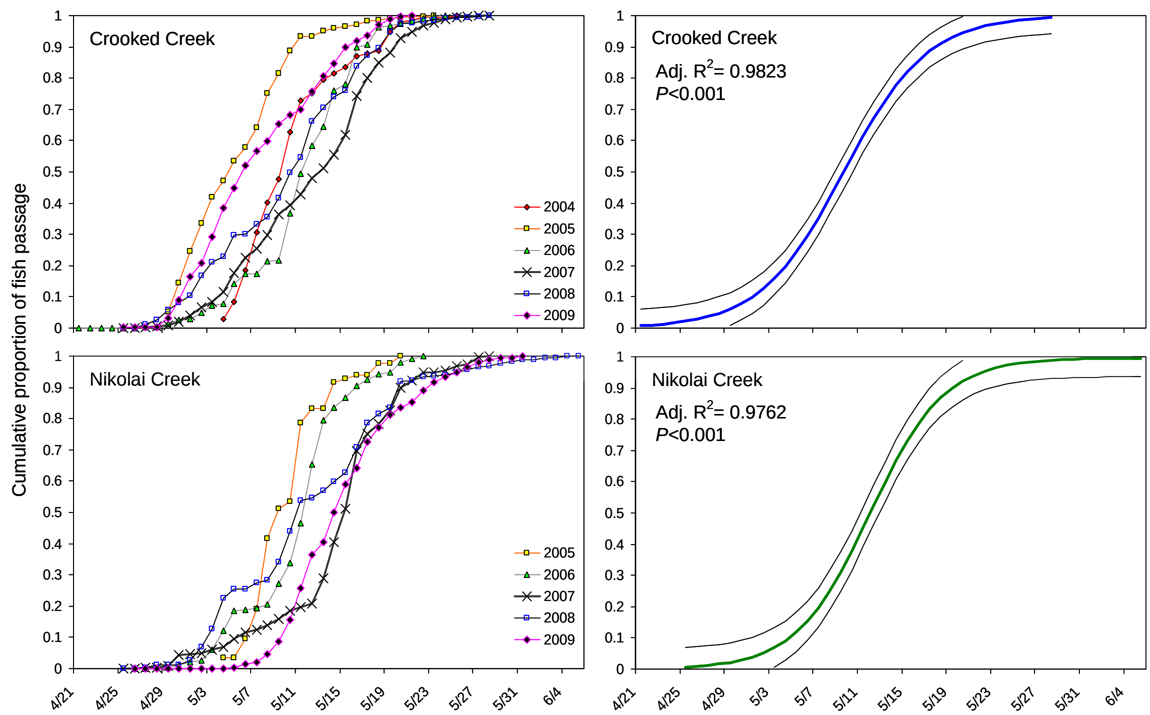

FIGURE 2. —The observed and modeled cumulative proportion of steelhead passage at Crooked and Nikolai creek weirs. Prediction intervals (95%) for the modeled run timing are denoted by black solid lines.

Timing of peak weekly passage at Crooked and Nikolai creeks varied among years, but consistently occurred between the first and second week of May from 2006-2009 (Figure 3; Appendices 3, 4, 5 and 6). The highest daily count at Crooked Creek (*N*=100) among all years occurred 12 May 2008, while the highest daily count at Nikolai Creek (*N*=105) occurred 16 May 2007 (Appendices 3 and 4).

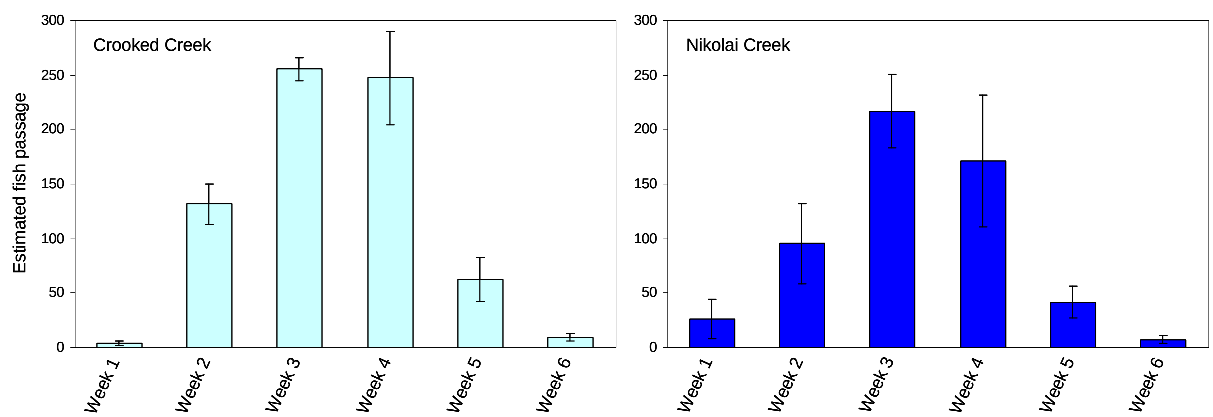

FIGURE 3. —Estimated mean weekly escapement of adult steelhead including standard errors in Crooked and Nikolai creeks between 2006 and 2009. Estimates and observations start on 25 April for both streams and end on 28 May for Crooked Creek and 5 June for Nikolai Creek. Years 2004 and 2005 were omitted because over half of the migratory period was not enumerated.

The average spawning escapement from 2006-2009 was 710 steelhead in Crooked Creek (range, 584-877) and 560 in Nikolai Creek (range, 451-660) (Figure 4; Appendices 3, 4, 5, and 6). The average steelhead escapement was significantly less (95% CI, 13%-30%) in Nikolai Creek than in Crooked Creek based on the estimated escapements which included estimates for missed days or incomplete counts.

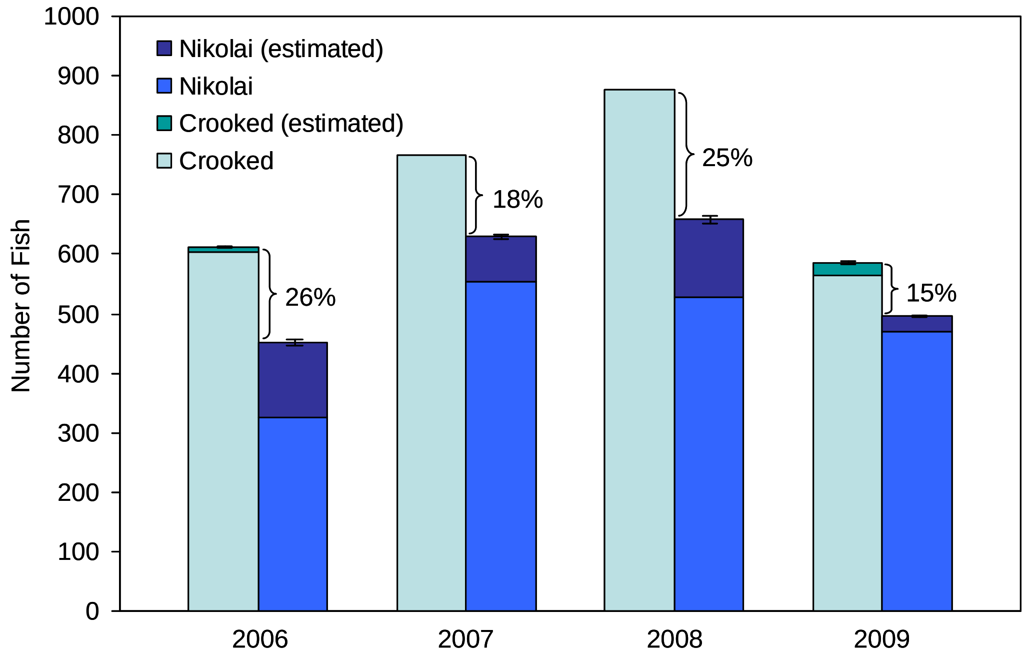

FIGURE 4. —Observed and estimated steelhead escapements in Crooked and Nikolai creeks between 2006 and 2009. Standard errors are only associated with the estimated portion of the escapements.

Age, sex, length.—A total of 405 ASL samples were collected from Crooked (*N*=296) and Nikolai (*N*=109) creeks between 2004 and 2009. Regenerated scales comprised about 14% (*N*=41) and 13% (*N*=14) of the scale samples from Crooked and Nikolai creeks, respectively. These scales were unreadable and omitted from any analysis. For the remaining 350 samples, freshwater ages could not be determined for 45% (*N*=116) of the 255 samples from Crooked Creek and 51% (*N*=48) of the 95 samples from Nikolai Creek (Appendices 7and 8), while saltwater ages and spawning events could be determined for all 350 samples.

Eighteen unique life history patterns were identified for steelhead returning to Crooked Creek (Table 1; Appendix 7). Freshwater ages at smoltification were not significantly different between males and females ($X^2 = 1.890$, df = 2, $P = 0.365$), and most (78%) migrated to saltwater as 3-year old fish. Similarly, there was no significant difference detected between the sexes ($X^2 = 0.597$, df = 2, $P = 0.954$) for saltwater ages prior to the first spawning event, and most spawned after spending either two (69%) or three (30%) years in saltwater. The number of spawning events, however, was significantly different between males and females ($X^2 = 23.875$, df = 4, $P < 0.001$), and most (66%) females were repeat spawners while most (66%) males spawned only once. Regardless of sex, few (12%) fish in the sample spawned more than twice.

Fifteen unique life history patterns were identified for steelhead returning to Nikolai Creek (Table 1; Appendix 8). As was found for Crooked Creek, freshwater ages at smoltification were not significantly different between sexes ($X^2 = 2.419$, df = 2, $P = 0.351$), however, a larger percentage migrated to saltwater as 4-year old (53%) fish than 3-year old (43%) fish. In contrast to Crooked Creek, a significant difference was found between the sexes ($X^2 = 0.597$, df = 2, $P < 0.001$) for saltwater ages prior to the first spawning event. Despite the fact that most fish did return to spawn after spending either two (41%) or three (57%) years in saltwater, most males (66%) returned to spawn after two years in saltwater, while most females (70%) returned after three years. Also in contrast to Crooked Creek, the number of spawning events was not significantly different between sexes ($X^2 = 23.875$, df = 4, $P < 0.001$), even though more females (57%) were repeat spawners than males (43%). Spawning beyond two events was similar to Crooked Creek with only 6% spawning more than twice.

Steelhead life histories for females tended to differ more between Crooked and Nikolai creeks than life histories for males (Table 1). Freshwater ages of females were significantly different ($X^2 = 44.179$, df = 3, $P < 0.001$) between creeks. Most females sampled at Nikolai Creek (61%) spent four years in freshwater before smolting whereas most females from Crooked Creek (77%) smolted after three years. Conversely, freshwater ages of males were not significantly different ($X^2 = 0.611$, df = 2, $P = 0.891$) between creeks, and most (72%) spent three years in freshwater before smolting. Similarly, saltwater ages of males prior to their first spawning event were not significantly different ($X^2 = 6.446$, df = 3, $P = 0.089$) between creeks with most (67%) males spending two years in saltwater before returning to spawn. However, saltwater ages of females prior to their first spawning event were significantly different ($X^2 = 39.033$, df = 3, $P < 0.001$) between creeks. Most (70%) females sampled at Nikolai Creek spent three years in saltwater prior to spawning for the first time, while most (70%) females at Crooked Creek spent only two years in saltwater. No significant difference was detected in the number of spawning events for females ($X^2 = 3.144$, df = 4, $P = 0.533$) between creeks as most (55%) females sampled spawned twice. Conversely, the number of spawning events for males were significantly different ($X^2 = 30.999$, df = 3, $P < 0.001$) between creeks. Most (66%) males sampled at Crooked Creek had spawned once, while most (89%) males sampled at Nikolai Creek had spawned twice.

TABLE 1. —Observed life histories of adult steelhead at Crooked and Nikolai Creeks.

			1.X		2.X		3.X		4.X		5.X		Total	
	Creek	Sex	*N*[ab]	%	*N*[ab]	%	*N*[ab]	%	*N*[ab]	%	*N*[ab]	%	*N*[ab]	%
Freshwater Age at Smolting	Nikolai	Male	0	0.0	0	0.0	9	56.3	6	37.5	1	6.3	16	100
		Female	0	0.0	0	0.0	11	35.5	19	61.3	1	3.2	31	100
	Crooked	Male	0	0.0	2	5.9	27	79.4	5	14.7	0	0.0	34	100
		Female	0	0.0	14	13.2	82	77.4	10	9.4	0	0.0	106	100
			X.1		X.2		X.3		X.4		X.5		Total	
			N[a]	%	*N*[a]	%	*N*[a]	%	*N*[a]	%	*N*[a]	%	*N*[a]	%
Saltwater Age at Maturity	Nikolai	Male	0	0.0	23	65.7	12	34.3	0	0.0	0	0.0	35	100
		Female	0	0.0	16	26.7	42	70.0	2	3.3	0	0.0	60	100
	Crooked	Male	1	0.0	46	67.6	21	30.9	0	0.0	0	0.0	68	100
		Female	1	0.0	130	69.5	56	29.9	0	0.0	0	0.0	187	100
			1		2		3		4		5		Total	
			N[a]	%	*N*[a]	%	*N*[a]	%	*N*[a]	%	*N*[a]	%	*N*[a]	%
Number of Spawning Events	Nikolai	Male	4	11.4	29	82.9	2	5.7	0	0.0	0	0.0	35	100
		Female	19	31.7	37	61.7	3	5.0	1	1.7	0	0.0	60	100
	Crooked	Male	45	66.2	19	27.9	2	2.9	2	2.9	0	0.0	68	100
		Female	63	33.7	98	52.4	22	11.8	3	1.6	1	0.5	187	100

[a] Fish with inconclusive ages were omitted from this table (Nikolai, *N* =14; Crooked, *N* =41)
[b] Fish with unreadable freshwater ages were omitted from this table (Nikolai, *N* =48; Crooked, *N* =116)

The sex composition of runs to both Nikolai and Crooked creeks was generally skewed towards males during the early portion of the run but then became skewed towards females for the remained of the run (Figure 5; Appendices 9 and 10). Female-to-male sex ratios were highest during 2004 (2.7:1) and 2005 (3.7:1) in Crooked Creek and during 2005 (4.9:1) and 2009 (2.1:1) in Nikolai Creek. These were years when the weir and video system were installed later in the year or when weir submergence caused gaps in observed counts. Sex ratios during the other years ranged between 1.1:1 and 1.7:1 in Crooked Creek (2006-2009) and were always 1.5:1 in Nikolai Creek (2006-2008). Females comprised 57% (95% CI, 51% – 65%) of the steelhead run in Crooked Creek during 2006-2009, and 60% (95% CI, 59% – 62%) of the run in Nikolai Creek from 2006-2008.

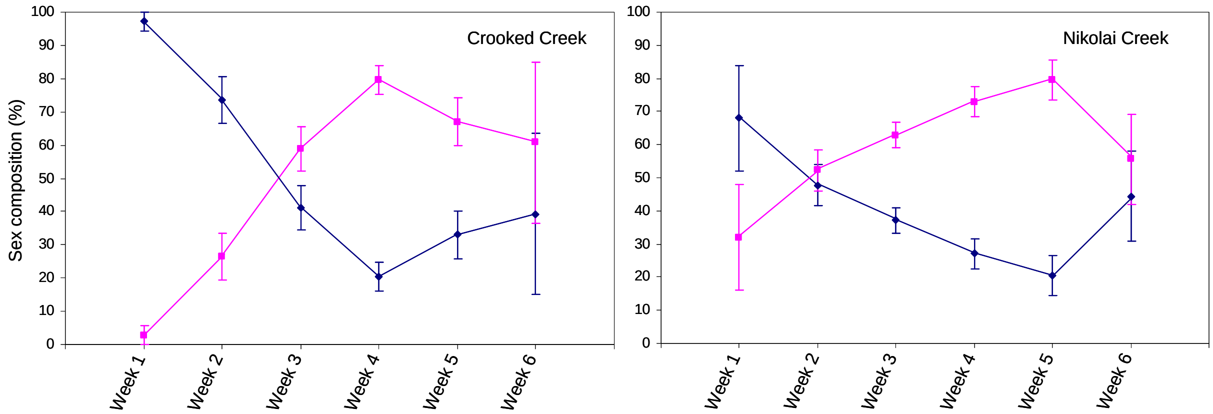

FIGURE 5. —Observed mean weekly sex composition including standard error of adult steelhead in Crooked and Nikolai creeks from 2004 to 2009. Females are represented by pink lines and males are represented by blue lines. Observations of fish started as early as 25 April and ended as late as 4 June. Appendices 3 and 4 illustrate specific start and end dates during each year.

Mean MEF lengths did not differ significantly among years for females in either creek (Crooked Creek, *P* = 0.098; Nikolai Creek, *P* = 0.971) and for males in Nikolai Creek (*P* = 0.076; Figure 6). However males sampled during 2004 in Crooked Creek (mean = 524 mm; 95% CI, 508 - 539) were significantly (*P* < 0.05) smaller than males sampled in all other years, and so were not included in the pooled sample for other analyses. The mean MEF length of the pooled male sample (mean = 606; 95% CI, 591 – 621) was significantly different (*P* < 0.05) than that of the pooled female sample (mean = 630; 95% CI, 623 – 637) for Crooked Creek, but not for Nikolai Creek. The mean MEF lengths of Nikolai Creek pooled male and pooled female samples were significantly greater (*P* < 0.05) than those of the corresponding pooled sex samples from Crooked Creek (Figure 6).

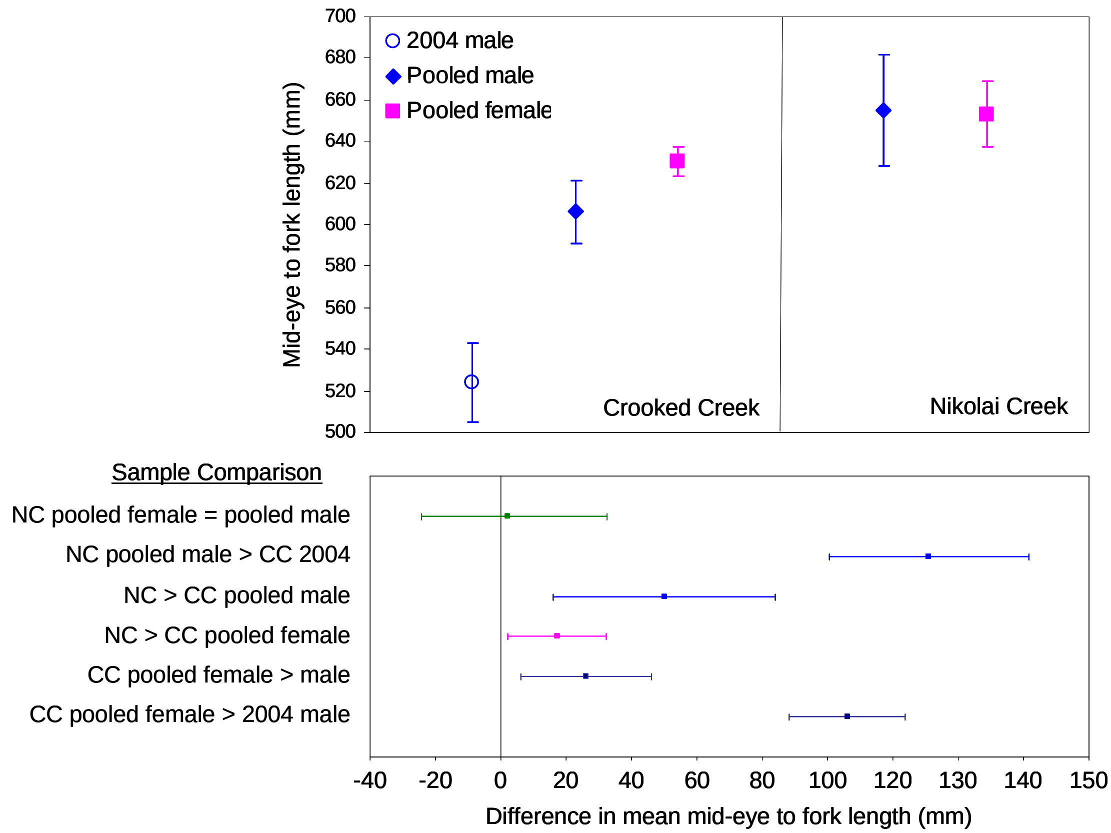

FIGURE 6. — Differences in mean lengths of male and female steelhead in Crooked and Nikolai Creeks including 95% confidence intervals for mean lengths.

Genetic analysis. —The *G*-test of allele frequency homogeneity showed no significant difference between inter-annual samples from Nikolai ($P > 0.77$) and Crooked ($P > 0.16$) creeks. Therefore, inter-annual samples were pooled for each location for remaining analyses. The mean estimates of expected heterozygosity (H_e) and allelic richness (A_r) were $H_e = 0.75$ and $A_r = 0.68$ for Nikolai Creek, $H_e = 0.67$ and $A_r = 8.7$ for Crooked Creek, and $H_e = 8.4$ and $A_r = 8.3$ for the Anchor River (Table 2). The Wilcoxon paired-sample test suggested that H_e is greater at Nikolai Creek than at Crooked Creek ($P < 0.001$) and the Anchor River ($P < 0.029$). The estimates of H_e did not differ between Crooked Creek and the Anchor River ($P > 0.710$). The estimates of A_r did not differ among the three populations. Five of 45 population x locus combinations deviated from Hardy-Weinberg equilibrium (HWE) at $\alpha = 0.05$ (Table 2). These instances were not specific to any one locus or population and the test results were not significant when the α-level was adjusted for multiple tests (45). Twenty-three of 315 tests for genotypic disequilibrium had *P*-values less than 0.05. No tests were considered significant when the α-level was adjusted for multiple tests (315).

The estimate of F_{ST} over all populations was 0.031 (95% CI, 0.020 - 0.041). The estimates of pairwise F_{ST} ranged from 0.019 (Crooked Creek x Anchor River) to 0.046 (Nikolai Creek x Anchor River, Table 3). The pairwise *G*-tests of allele frequency homogeneity indicated significant ($P < 0.017$) genetic differentiation among all three populations.

TABLE 2. —Genetic diversity at 15 microsatellite loci[a] in Kenai Peninsula collections of steelhead from Nikolai Creek[b], Crooked Creek[b] and the Anchor River. Variables (Var) = sample size (*n*), expected heterozygosity (H_E), observed heterozygosity (H_O), allele richness (A_R). An asterisk indicates $P < 0.05$ that the sample conforms to Hardy-Weinberg expectation. None of the *P*-values were judged significant when the α-level (0.05) was adjusted for a table-wide test using the sequential Bonferroni technique (α =0.017) (Rice 1989).

		Loci															
Location	Var	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	avg
Nikolai Ck.	*n*	107	106	108	106	108	108	106	106	108	106	108	107	108	108	108	107.2
	H_E	0.66	0.66	0.85	0.85	0.84	0.88	0.77	0.83	0.66	0.75	0.68	0.59	0.50	0.87	0.80	0.75
	H_O	0.62	0.63	0.82	0.83	0.81	0.89	0.76	*0.75	0.67	0.77	0.70	0.57	0.52	*0.69	0.81	0.72
	A_r	5.0	7.8	10.9	11.7	9.0	12.9	6.0	16.6	5.0	8.8	4.0	7.0	2.0	12.0	11.9	8.7
Crooked Ck.	*n*	159	160	160	156	156	159	153	155	160	154	158	159	156	158	160	157.5
	H_E	0.65	0.51	0.70	0.84	0.82	0.85	0.55	0.79	0.64	0.70	0.64	0.41	0.49	0.81	0.81	0.68
	H_O	0.72	0.48	0.70	0.83	*0.77	0.82	0.51	0.80	0.63	0.66	0.68	0.44	*0.42	0.80	0.83	0.67
	A_r	5.5	4.6	10.5	11.2	11.8	12.4	5.8	17.2	5.0	8.8	4.0	5.0	2.8	12.1	9.4	8.4
Anchor R.	*n*	95	95	95	95	95	95	95	94	95	95	95	95	95	95	95	94.9
	H_E	0.62	0.44	0.68	0.88	0.84	0.73	0.55	0.88	0.62	0.77	0.65	0.43	0.50	0.75	0.81	0.67
	H_O	0.61	0.40	0.74	0.82	0.83	0.69	*0.45	0.82	0.57	0.72	0.65	0.43	0.60	0.83	0.79	0.66
	A_r	4.0	5.0	8.0	14.0	13.0	10.0	6.0	14.0	5.0	11.0	5.0	6.0	3.0	10.0	10.0	8.3

[a] Loci 1-15 in order: *Ogo4* (Olsen et al. 1998); *Oke4* (Buchholz et al. 1999); *Oki23* (Smith et al. 1998); *OMM1046* (Rexroad III et al. 2002); *Omy1001, Omy1011* (Spies et al. 2005); *Omy7* (Gharbi, unpub., Univ. of Guelph, Guelph, Ontario, CA); *One102* (Olsen et al. 2000); *Oneu14* (Scribner et al. 1996); *Ots100* (Nelson and Beacham 1999); *Ots3M* (Greig and Banks 1999); *Ots4* (Banks et al. 1999); *Ssa289* (McConnell et al. 1995); *Ssa407, Ssa408* (Cairney et al. 2000).

[b] The Nikolai Creek samples were collected in 2008 and 2009 and the Crooked Creek samples were collected in 2006 and 2008. The temporal replicates from each location were pooled because the test of allele frequency homogeneity showed no significant difference across years. The Anchor River samples were collected in 2008.

TABLE 3. —Pairwise estimates of F_{ST} and P-values from the G-test of allele frequency homogeneity. Results reflect variation among sample locations at 15 microsatellite loci (α corrected for multiple tests=0.017).

Sample pair	F_{st}	G-test *P*-values
Nikolai Creek x Crooked Creek	0.032	< 0.017
Nikolai Creek x Anchor River	0.046	<0.017
Crooked Creek x Anchor River	0.019	<0.017

Environmental. —Mean water temperatures recorded between 26 April and 30 May in Crooked and Nikolai creeks were used to describe the water temperatures during the migratory periods; annual mean temperatures between 2005 and 2009 ranged from 5.1 to 8.8°C in Crooked Creek and from 3.0 to 6.6°C in Nikolai Creek (Appendix 11). Mean water temperatures in Nikolai Creek were 1.6 to 2.6°C colder (95% CI; $P < 0.001$) than Crooked Creek. Based on the models we fitted, the steelhead migration is predicted to start once mean daily water temperature reach 1.4°C in Crooked (95% CI, 0.04 - 2.9°C) and Nikolai (95% CI, 0.8 to 2.0°C) creeks. Once the spawning migration was initiated, the proportion of fish passage at Crooked Creek gradually increased with water temperature and was predicted to peak at 4.5°C (95% PI, ±0.4°C). In comparison, 74% (95% PI, ±23%) of the fish passage at Nikolai Creek occurred between 0 and 3°C, peaking at 2.7°C (95% PI, ±1.2) before sharply dropping off (Figure 7).

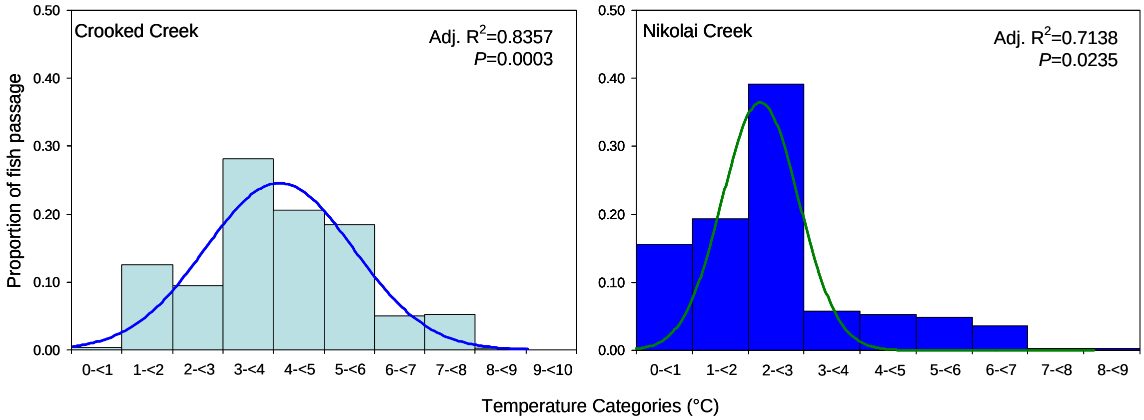

FIGURE 7. —Proportion of total observed fish passage during all years of operation in Crooked and Nikolai creeks at categorized mean daily water temperatures. Observed values are represented by solid bars and the modeled relationship is represented by the solid line.

Discussion

Because of the variation in life history patterns observed in adult steelhead at Crooked and Nikolai creeks, the number of returning adults reflect environmental and habitat conditions for the previous 5+ years, rather than a single year. Therefore, we would expect abundance estimates to vary only slightly from year to year. Steelhead abundance at each creek was typically composed of several hundred fish with conservative estimates during 2004 and 2005 in Crooked Creek and 2005 in Nikolai Creek because of delayed project start dates. Because we likely missed a large percentage of fish early in the spawning migration during these two years, no attempt was made to estimate or analyze passage for those periods. Since 2005, project start dates in both Crooked and Nikolai creeks were generally initiated prior to ice out and the observed estimates are thought to be relatively accurate, even though we experienced some intermittent fish counts at times in each creek. Intermittent fish counts were more common at Nikolai Creek due to both its more remote location and the more controlled conditions at the Crooked Creek weir, which incorporated the use of an existing fish hatchery facility. Periods of lost or intermittent fish counts at Crooked Creek were caused by early termination of weir operations for hatchery maintenance, while periods of lost or intermittent fish counts at Nikolai Creek were due to effects of high water and debris loads on the Nikolai Creek weir. In particular, spring flooding influenced the number of days with no or incomplete counts at Nikolai Creek and ultimately the extent of estimated passage in a given year.

Sex ratios of female-to-male steelhead were similar among most years within creeks with females comprising most of the spawning escapement. Observations of larger proportions of females to males are common and have been reported for several steelhead populations returning to river systems throughout Alaska and the Pacific Northwest (Kesner and Barnhart 1972; Sanders 1985; Lohr and Bryant 1999; Love and Harding 2009). The higher proportion of females observed during spawning migrations is likely related to their greater success at surviving spawning events, which commonly enables them to spawn more than once. Conversely, males tend to remain on the spawning grounds longer (Jones 1974), and exert more energy tending to multiple females throughout the spawning period (Meigs and Pautzke 1941), which generally results in males having a higher spawning mortality than females (Shapovalov and Taft 1954; Gates 2009).

Sex ratios observed during 2004 and 2005 in Crooked Creek and 2005 and 2009 in Nikolai Creek were highly skewed towards females. We think these skewed ratios were a sampling artifact since we were unable to monitor the early portion of the runs in these years, and these ratios were inconsistent with those we obtained in years with better temporal coverage as well as ratios reported for other steelhead populations (Sumner 1948; Withler 1966; Love and Harding 2009). Sheppard (1972) also suggested that steelhead returning to streams along the Pacific coast from California to Alaska exhibit sex ratios of 1:1. Our observations showed that males tend to dominate the early part of the run, which is difficult to sample since it occurs during the ice-out period. Similar observations of differential run timing between sexes have been reported for other streams in California, Oregon, and Southeast Alaska (Chapman 1958; Bali 1959; Withler 1966; Love and Harding 2009). Therefore, we feel comfortable in treating these skewed sex ratios as sampling artifacts rather than actual spawning population anomalies.

Steelhead sampled in Crooked and Nikolai creeks exhibited a diverse array of life-history patterns with variations in smolt age, saltwater residence, and spawning activity. Other investigators have also found diverse life history patterns for steelhead populations, including populations in Petersburg Creek, Southeast Alaska (Jones 1972 and 1974) and several river systems in British Columbia, Canada (Withler 1966). Most steelhead in Crooked Creek, regardless of sex, smolted after three years in freshwater and spawned for the first time after spending two years in saltwater. These findings are congruent with observations made by Sanders (1985) of other wild steelhead populations in Alaska. However, we found differences from this general pattern for female steelhead in Nikolai Creek–these fish spent four years in freshwater prior to smolting and three years in saltwater before returning to spawn for the first time. While no statistically significant difference was detected in freshwater life-history patterns of male steelhead sampled in Nikolai Creek compared to females in the same creek or males from Crooked Creek, we suspect that with a larger sample there would have been a difference. The percent of male fish from Nikolai Creek residing four years in freshwater was two times greater than those sampled at Crooked Creek (Table 1). This additional year in freshwater could be attributed to colder water conditions in Nikolai Creek. The incubation period for steelhead eggs increases with lower water temperatures (Barnhart 1986), and this would affect the hatching time and ultimately the size of juveniles going into their first winter. Royal (1972) reported that time of stocking and size of fish during the release of hatchery-reared steelhead affected the length of freshwater residency. Water temperatures also affect the metabolism and physical capabilities of juvenile steelhead at different rates depending on the time of year and life stage (Reiser and Bjornn 1979; Pauley et al. 1986). Spending an extra year in freshwater as a juvenile could be one of many possible reasons Nikolai Creek supports a smaller return of adults than Crooked Creek. Residing in freshwater for an additional year invariably makes these fish susceptible to increased predation and competition by other species that likely results in lower overall freshwater survival.

Saltwater residence time prior to the first spawning event also varied between creeks and sexes. Most female steelhead sampled at Nikolai Creek spent three years in saltwater before maturing and spawning for the first time, whereas the majority of males sampled in the Nikolai Creek and most males and females sampled at Crooked Creek matured after spending only two years in saltwater. Steelhead populations in the Pacific Southwest are reported to mature after one to two years in saltwater (Barnhart 1986), while populations in the Pacific Northwest mature after two to three years in saltwater (Shapovalov and Taft 1954). This is also consistent with Withler's (1966) reports of saltwater residence times increasing from south to north for steelhead populations. Although we do not know why females in Nikolai Creek needed an additional year in saltwater to mature, we suspect it could have been related to their size at smolting. Because growth rates of steelhead are highest during the first year in freshwater and saltwater (Meigs and Pautzke 1941; Barnhart 1986; Pauley et al. 1986), fish spending similar time in freshwater as a juvenile from Nikolai Creek might be emigrating to saltwater at a smaller size than those from Crooked Creek.

Unlike other *Oncorhynchus* species, not all steelhead die after spawning but their ability to repeat spawn decreases with each spawning event. Females exhibited a higher rate of repeat spawning than males, which is at least partly due to a higher post-spawning mortality rate for males. For example, we (Gates and Boersma 2010) found higher mortality rates for male steelhead spawning throughout the Kasilof River watershed during 2008 and 2009. The ability to spawn more than once is also thought to be related to the survival of steelhead kelts emigrating to sea following spawning, as was reported by Ward and Slaney (1988) for kelts in the Keogh River on Vancouver Island, British Columbia, Canada. We found that most male steelhead sampled from Crooked Creek were first time spawners (66%), while most males sampled from Nikolai Creek were on their second spawning migration. This difference could be a result of different kelt survival rates since, on average, steelhead spawning in Tustumena Lake tributaries took much longer to emigrate to saltwater (19 d) than those spawning in Crooked Creek (7 d; Gates and Boersma 2010). As a result of their longer emigration, kelts from Tustumena Lake tributaries could be in better condition and have greater survival rates when they re-enter saltwater than kelts from Crooked Creek. The higher rate of repeat spawning among males from Nikolai Creek could also be related to the timing of their freshwater entrance and subsequently the amount of time they spend in freshwater prior to spawning. Withler (1966) reports that the incidence of repeat spawning may be associated with the length of time spent in freshwater prior to spawning and that repeat spawning is ultimately higher in winter/spring run steelhead populations. Finally, a longer emigration period may also allow kelts from Tustumena Lake tributaries to avoid being captured during the personal-use sockeye salmon gillnet fishery that occurs near the mouth of the Kasilof River between 15 and 24 June. This fishery coincides with the period of kelt emigration (Gates and Boersma 2010), but kelts from Tustumena Lake tributaries may travel through this area towards the end of or after the fishery ends.

We found two notable differences in the MEF lengths of sampled steelhead. First, steelhead sampled during 2004 in Crooked Creek were the smallest steelhead measured during this project. We attribute this to the late project start date that prevented us from sampling the early portion of the spawning run, which is typically dominated by males. Second, females and males from Nikolai Creek were the largest steelhead sampled during the project. We suspect that because most Nikolai Creek females resided in saltwater for three years prior to maturity they were able to attain larger sizes than the typical Cooked Creek female that spent only two years in saltwater prior to spawning for the first time. Meigs and Pautzke (1941) reported that most of the steelhead they sampled that were over 12 pounds had spent three to four years in saltwater prior to reaching maturity. This agrees with Withler's (1966) later finding that length at maturity is related to saltwater residence time. Our observation of Nikolai Creek males being larger than Crooked Creek males may be due to the greater number of male repeat spawners sampled at Nikolai Creek which could also be indicative of the presence of a winter/spring run component in Nikolai Creek or higher survival of kelts.

We documented significant variation both within and among Nikolai Creek, Crooked Creek, and Anchor River steelhead populations as well as a greater genetic similarity between Crooked Creek and Anchor River than between Crooked Creek and Nikolai Creek populations. The evaluation of expected heterozygosity (H_e) suggested the Nikolai Creek population has higher intra-population diversity than either the Crooked Creek or Anchor River populations based on the Wilcoxon paired-sample test. In addition, the estimates of pairwise F_{ST} also suggested Crooked Creek fish are more closely related to Anchor River fish than to Nikolai Creek fish. The relationship between Crooked Creek and the Anchor River steelhead populations most likely stems from the use of Anchor River broodstock in the early 1980's as a source of fertilized eggs to begin the Crooked Creek enhancement program.

Despite differences in water temperature regimes between Crooked and Nikolai creeks, steelhead spawning migration began at similar dates and appears to be triggered by a minimum water temperature threshold. Once the spawning migration began, the run timing continued in a normal pattern at both creaks, while mean daily water temperatures varied among creeks. Water temperatures on average did not reach 2°C until 30 April in Nikolai Creek, five days later than the 2°C average in Crooked Creek (Appendix 11). The proportion of fish passage at Crooked Creek increased gradually with water temperature and peaked at 3 to 5°C; in comparison, at Nikolai Creek passage peaked at 2 to 3°C, and then sharply dropped off (Figure 7). These patterns indicate that water temperature probably has little effect on run timing once the minimum threshold is achieved for initiation. Other studies have also noted that water temperature and discharge are important environmental factors influencing the initiation of upstream movement of steelhead (Shapovalov and Taft 1954; Jones 1972; Kesner and Barnhart 1972; Burgner et al. 1992). The differences in water temperatures observed between the two creeks are likely due to the different drainage areas. Crooked Creek drains more lowland areas whereas Nikolai Creek drains higher elevations which typically have higher snow pack.

Steelhead populations present in the Kasilof River watershed are relatively small in numbers when compared to the returns of Pacific salmon within the same watershed. While steelhead abundance is limited by environmental conditions and available spawning and rearing habitat, human induced factors also play a role. The spring steelhead and in-river Chinook salmon sport fisheries and personal-use sockeye salmon gillnet fishery overlap substantially with the steelhead spawning migration and kelt emigration (Gates and Boersma 2010). The effects these fisheries have on Crooked and Nikolai creek steelhead populations are unknown, but they could be greater than they are currently thought to be. Federal subsistence salmon fisheries in the Kasilof River also overlap substantially with the fall immigration of steelhead (Gates and Boersma 2010), and, while few people have participated since these fisheries began in 2007, the potential for steelhead handling mortality exists if participation increases or a fish wheel is operated.

Conclusion

- Video weirs are a cost effective and reliable tool to passively monitor steelhead populations.
- Steelhead return to spawn in Crooked Creek in greater numbers than Nikolai Creek but run timing at both creeks are similar and generally occur during the first and second week of May.
- Regardless of the creek, males tend to dominate the early portion of the run before quickly switching to a predominately female component. Overall, sex ratios are generally skewed towards females.
- Steelhead returning to spawn in Crooked and Nikolai creeks exhibited up to eighteen different life history traits with significant differences in age and size of steelhead.

- Crooked Creek steelhead primarily smolt at age three and mature after two years in saltwater whereas Nikolai Creek fish mostly smolt at age four and mature after three years.
- Nikolai Creek steelhead tend to be larger than Crooked Creek steelhead regardless of sex, and females from Crooked Creek are on average larger than males from the same creek. Lengths of male and female steelhead in Nikolai Creek did not differ.
- Comparisons of tissue samples collected from Crooked Creek, Nikolai Creek, and the Anchor River were genetically different from one another and pairwise *Fst* tests indicated that Crooked Creek steelhead were more closely related to the Anchor River than to Nikolai Creek.
- Water temperatures recorded during the spawning migration were significantly colder in Nikolai Creek than in Crooked Creek.

Recommendations

Several additional investigations could be conducted to advance our understanding and refine the management of steelhead populations present in the Kasilof River watershed and other Kenai Peninsula streams. Future investigations within the Kasilof River watershed should include:

- Continuation of abundance and run time monitoring for steelhead spawning populations on the Kenai Peninsula, including collection of age, sex and length information.
- Expansion of the genetic baseline for steelhead spawning populations found throughout the Kenai Peninsula and Cook Inlet so that differences in mixed stock samples can be detected with a reasonable level of accuracy and precision.
- Estimation of steelhead smolt production and survival, smolt-to-adult survival, and documentation of freshwater distribution and habitat use by juvenile steelhead in the Kasilof River watershed.
- Description of the behavior and survival of post-spawn steelhead kelts, as well as their coastal distribution as they re-enter Cook Inlet.
- Estimation of the impact of existing sport and personal use fisheries on steelhead survival.
- Determination of freshwater entry times for specific spawning groups of steelhead spawning within the Kasilof River watershed.

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References

Agresti, A. 2002. Categorical data analysis, 2nd edition. John Wiley & Sons, Hoboken, New Jersey.

Bali, J. M. 1959. Scale analyses of steelhead, *Salmo gairdnerii gairdnerii* Richardson, from various coastal watersheds of Oregon. Master's thesis. Oregon State College, Corvallis.

Banks, M. A., M.S. Blouin, B.A. Baldwin, and V.K. Rashbrook. 1999. Isolation and inheritance of novel microsatellites in Chinook salmon (*Oncorhynchus tshawytscha*). Journal of Heredity 90:281-288. See erratum May/June 1999 for primer sequence corrections.

Barnhart, R.A. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) – steelhead. U.S. Fish and Wildlife Service, Biological Report 82 (11.60). U.S. Army Corps of Engineers, TR EL-82-4. 21 pp.

Bates, D. M. and J. M. Chambers. 1992. Nonlinear models. Pages 422-453 *in* Chambers, J. M. and T. J. Hastie, editors. Statistical Models in S. Chapman and Hall/CRC, Boca Raton, Florida.

Begich, R. N. 1997. Assessment of the 1995 return of steelhead to the Karluk River, Alaska. Alaska Department of Fish and Game, Fishery Data Series Number 97-6, Anchorage, Alaska.

Buchholz, W. S., J. Miller, and W.J. Spearman. 1999. Summary of PCR primers for salmonid genetic studies. U.S. Fish and Wildlife Service, Alaska Fisheries Progress Report 99-1.

Burgner, R. L., J. T. Light, L. Margolis, T. Okazaki, A. Tautz, and S. Ito. 1992. Distribution and origins of steelhead (*Oncorhynchus mykiss*) in offshore waters of the North Pacific Ocean. International North Pacific Fisheries Commission Bulletin 51, Vancouver, British Columbia, Canada.

Cairney, M., J. B. Taggart, and B. Hoyheim. 2000. Characterization of microsatellite and minisatellite loci in Atlantic salmon (*Salmo salar L.)* and cross-species amplification in other salmonids. Molecular Ecology 9:2175-2178.

Chapman, D. W. 1958. Studies on the life history of Alsea River steelhead. Journal of Wildlife Management 22(2):123-134.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.

Gamblin, M., L. E. Marsh, P. Berkhahn, and S. Sonnichsen. 2004. Area management report for the recreational fisheries of the northern Kenai Peninsula, 2000-2001. Alaska Department of Fish and Game, Fishery Management Report Number 04-04, Soldotna, Alaska.

Gates, K. S., and D. E. Palmer. 2006a. Abundance and run timing of adult steelhead trout in Crooked and Nikolai Creeks, Kenai Peninsula, Alaska, 2005. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2006-5, Kenai, Alaska.

Gates, K. S., and D. E. Palmer. 2006b. Abundance and run timing of adult steelhead trout in Crooked and Nikolai Creeks, Kenai Peninsula, Alaska, 2006. U.S. Fish and Wildlife

Service, Kenai Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2006-13, Kenai, Alaska.

Gates, K. S., and D. E. Palmer. 2008. Abundance and run timing of adult steelhead trout in Crooked and Nikolai Creeks, Kenai Peninsula, Alaska, 2007. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2008-2, Kenai, Alaska.

Gates, K. S. 2009. Spawning and seasonal distribution of adult steelhead in the Kasilof River watershed, Alaska, 2007 and 2008. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2009-11, Soldotna, Alaska.

Gates, K. S., and J. K. Boersma. 2009. Abundance and run timing of adult steelhead trout in Crooked and Nikolai Creeks, Kenai Peninsula, Alaska, 2008. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2009-2, Soldotna, Alaska.

Gates, K. S and J. K. Boersma. 2010. Spawning and seasonal distribution of adult steelhead in Southcentral Alaska's Kasilof River watershed from 2007 to 2009. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office, Alaska Fisheries Data Series Report 2010-06, Soldotna, Alaska.

Goudet, J. 2001. FSTAT, a program to estimate and test gene diversities and fixation indices, version 2.9.3. Available from http://www.unil.ch/izea/softwares/fstat.html.

Greig, C. and M. A. Banks. 1999. Five multiplexed microsatellite loci for rapid response run identification of California's endangered winter Chinook salmon. Animal Genetics 30:316-324.

Howe, A. L., G. Fidler, and M. J. Mills. 1995. Harvest, catch, and participation in Alaska sport fisheries during 1994. Alaska Department of Fish and Game, Fishery Data Series Number 95-24, Anchorage, Alaska.

Howe, A. L., G. Fidler, A. E. Bingham, and M. J. Mills. 1996. Harvest, catch, and participation in Alaska sport fisheries during 1995. Alaska Department of Fish and Game, Fishery Data Series Number 96-32, Anchorage, Alaska.

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001a. Revised Edition: Harvest, catch, and participation in Alaska sport fisheries during 1996. Alaska Department of Fish and Game, Fishery Data Series Number 97-29 (revised), Anchorage, Alaska.

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001b. Revised Edition: Harvest, catch, and participation in Alaska sport fisheries during 1997. Alaska Department of Fish and Game, Fishery Data Series Number 98-25 (revised), Anchorage, Alaska.

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001c. Revised Edition: Participation, catch, and harvest in Alaska sport fisheries during 1998. Alaska Department of Fish and Game, Fishery Data Series Number 99-41 (revised), Anchorage, Alaska.

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001d. Participation, catch, and harvest in Alaska sport fisheries during 1999. Alaska Department of Fish and Game, Fishery Data Series Number 01-8, Anchorage, Alaska.

Jennings, G. B., K. Sundet, A. E. Bingham, and D. Sigurdsson. 2004. Participation, catch, and harvest in Alaska sport fisheries during 2001. Alaska Department of Fish and Game, Fishery Data Series Number 04-11, Anchorage, Alaska.

Jennings, G. B., K. Sundet, A. E. Bingham, and D. Sigurdsson. 2006a. Participation, catch, and harvest in Alaska sport fisheries during 2002. Alaska Department of Fish and Game, Fishery Data Series Number 06-34, Anchorage, Alaska.

Jennings, G. B., K. Sundet, A. E. Bingham, and D. Sigurdsson. 2006b. Participation, catch, and harvest in Alaska sport fisheries during 2003. Alaska Department of Fish and Game, Fishery Data Series Number 06-44, Anchorage, Alaska.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2007. Participation, catch, and harvest in Alaska sport fisheries during 2004. Alaska Department of Fish and Game, Fishery Data Series Number 07-40, Anchorage, Alaska.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2009a. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2005. Alaska Department of Fish and Game, Fishery Data Series Number 09-47, Anchorage, Alaska.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2009b. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2006. Alaska Department of Fish and Game, Fishery Data Series Number 09-54, Anchorage, Alaska.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2010a. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2007. Alaska Department of Fish and Game, Fishery Data Series Number 10-02, Anchorage, Alaska.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2010b. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2008. Alaska Department of Fish and Game, Fishery Data Series Number 10-22, Anchorage, Alaska.

Johnson, J., and M. Daigneault. 2008. Catalog of waters important for spawning, rearing, or migration of anadromous fishes – Southcentral Region, Effective June 2, 2008. Alaska Department of Fish and Game, Special Publication Number 08-05, Anchorage, Alaska.

Jones, D. E. 1972. A study of steelhead-cutthroat trout in Alaska. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Progress Report 1971-1972, Project F-9-4, Volume 13 (G-II-I): 91-108, Juneau, Alaska.

Jones, D. E. 1974. The study of cutthroat-steelhead in Alaska. Alaska Department of Fish and Game, Annual Performance Report Number AFS-42.

Jones, R. N., and D. A. Faurot. 1991. Investigations of resident fish in Tustumena Lake, Kenai National Wildlife Refuge, Alaska, 1987. U.S. Fish and Wildlife Service, Alaska Fisheries Technical Report Number 14, Kenai, Alaska.

Kesner, W. D., and R. A. Barnhart. 1972. Characteristics of the fall-run steelhead (*Salmo gairdnerii gairdnerii*) of the Klamath River system with emphasis on the Half-Pounder'. California Fish and Game 58(3): 204-220.

Koo, T. S. Y. 1962. Age determination in salmon. Pages 37-48 *in* T.S.Y. Koo, editor. Studies of Alaskan red salmon. University of Washington Press, Seattle, Washington.

Larson, L. L., and D. T. Balland. 1989. Statistics for selected sport fisheries on the lower Kenai Peninsula, Alaska, during 1988 with the emphasis on Dolly Varden char. Alaska Department of Fish and Game, Fishery Data Series Number 101, Juneau, Alaska.

Lindsay, R. B., K. R. Kenaston, and R. K. Schroeder. 1991. Steelhead production factors. Oregon Department of Fish and Wildlife, Fish Research Project F-120-R, Annual Progress Report, Portland, Oregon.

Lohr, S. C., and M. D. Bryant. 1999. Biological characteristics and population status of steelhead (Oncorhynchus mykiss) in Southeast Alaska. U.S. Forest Service, Pacific Northwest Research Station, General Technical Report, PNW-GTR-407, Portland, Oregon.

Love, D. C., and R. D. Harding. 2009. Steelhead trout production studies at Sitkoh Creek, Alaska, 2005-2006. Alaska Department of Fish and Game, Fishery Data Series Number 09-68, Anchorage, Alaska.

McConnell, S., L. Hamilton, D. Morris, D. Cook, D. Paquet, P. Bentzen, and J. Wright. 1995. Isolation of salmonid microsatellite loci and their application to the population genetics of Canadian east coast stocks of Atlantic salmon. Aquaculture 137:19-30.

Meigs, R. C. and C. P. Pautzke. 1941. Additional notes on the life history of the Puget Sound steelhead (*Salmo gairdneri*). State of Washington Department of Game, Biological Bulletin 5: 13.

Mills, M. J. 1988. Alaska statewide sport fisheries harvest report, 1988. Alaska Department of Fish and Game, Fishery Data Series Number 122, Juneau, Alaska.

Mills, M. J. 1989. Alaska statewide sport fisheries harvest report, 1987 data. Alaska Department of Fish and Game, Fishery Data Series Number 52, Juneau, Alaska.

Mills, M. J. 1990. Harvest, catch, and participation in Alaska sport fisheries during 1989. Alaska Department of Fish and Game, Fishery Data Series Number 90-44, Anchorage, Alaska.

Mills, M. J. 1991. Harvest, catch, and participation in Alaska sport fisheries during 1990. Alaska Department of Fish and Game, Fishery Data Series Number 91-58, Anchorage, Alaska.

Mills, M. J. 1992. Harvest, catch, and participation in Alaska sport fisheries during 1991. Alaska Department of Fish and Game, Fishery Data Series Number 92-40, Anchorage, Alaska.

Mills, M. J. 1993. Harvest, catch, and participation in Alaska sport fisheries during 1992. Alaska Department of Fish and Game, Fishery Data Series Number 93-42, Anchorage, Alaska.

Mills, M. J. 1994. Harvest, catch, and participation in Alaska sport fisheries during 1993. Alaska Department of Fish and Game, Fishery Data Series Number 94-28, Anchorage, Alaska.

Moser, E. 1998. Water resource inventory and assessment, Kenai National Wildlife Refuge, 1997 stream discharge gauging data. U.S. Fish and Wildlife Service, Water Resource Branch, WRB 98-01, Anchorage, Alaska.

Mosher, K. H. 1968. Photographic atlas of sockeye salmon scales. U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Fishery Bulletin Number 2:243-274.

Mosher, K. H. 1969. Identification of Pacific salmon and steelhead by scale characteristics. United States Department of the Interior, U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Circular 317, Washington, D.C.

Nelson, R. J. and T. D. Beacham. 1999. Isolation and cross species amplification of microsatellite loci useful for study of Pacific salmon. Animal Genetics 30:228-229.

Olsen, J. B., P. Bentzen, and J. E. Seeb. 1998. Characterization of seven microsatellite loci derived from pink salmon. Molecular Ecology 7:1087-1089.

Olsen, J. B., S. L. Wilson, E. J. Kretschmer, K. C. Jones, and J. E. Seeb. 2000. Characterization of 14 tetranucleotide microsatellite loci derived from sockeye salmon. Molecular Ecology 9:2185-2187.

Palmer, D. E. 2003. Estimation of sockeye salmon escapement into McLees Lake, Unalaska Island, Alaska, 2002. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office, Alaska Fisheries Data Series Report Number 2003-4, Kenai, Alaska.

Pauley, G. B., B. M. Bortz, and M. F. Shepard. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) – steelhead trout. U.S. Fish and Wildlife Service, Biological Report 82 (11). U.S. Army Corps of Engineers, TR EL-82-4. 24 pp.

RDCT (R Development Core Team). 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Reiser, D. W. and T. C. Bjornn. 1979. Habitat requirements of anadromous salmonids. 54 pp. *in* W.R. Meehan, editor. Influence of forest and rangeland management on anadromous fish habitat in western North America. U.S. Department of Agriculture, Pacific Northwest Forest and Range Experimental Station, General Technical Report PNW-96, Portland, Oregon.

Rexroad III, C. E., R. L. Coleman, A. L. Gustafon, W.K. Hershberger, and J. Killefer. 2002. Development of rainbow trout microsatellite markers from repeat enriched libraries. Marine Biotechnology 3: 12-16.

Rice, W. R. 1989. Analyzing tables of statistical tests. Evolution 43:223-225.

Robards, M. D. and T. P. Quinn. 2002 The migratory timing of adult summer-run steelhead in the Columbia River over six decades of environmental change. Transactions of the American Fisheries Society 131: 523-536.

Royal, L. A. 1972. An examination of the anadromous trout program of the Washington State Game Department. Washington State Department of Game, Final Report AFS-49, 176 pages, Olympia, Washington.

Sanders, G. 1985. Summary of age, sex, run timing, and length-weight characteristics of Alaska steelhead. Pages 29-49 *in* Alaska Department of Fish and Game, Alaska Steelhead Workshop 1985, unpublished manuscript, 134 p. (Available from Alaska Resources Library and Information Services, ARLIS Room 111, Library Building, 3211 Providence Drive, Anchorage, Alaska 99508).

Scribner, K. T., J. R. Gust, and R. L. Fields. 1996. Isolation and characterization of novel microsatellite loci: cross-species amplification and population genetic applications. Canadian Journal of Fisheries and Aquatic Sciences 53:685-693.

Shapovalov, L., and A. C. Taft. 1954. The life histories of steelhead rainbow trout (Salmo gairdnerii gairdnerii) and silver salmon (Oncorhynchus kisutch) with special reference to Waddell Creek, California, and recommendations regarding their management. California Department of Fish and Game, Fish Bulletin 98.

Sheppard, D. 1972. The present status of the steelhead trout stocks along the Pacific coast. 519-556 *in* D.H. Rosenburg, editor. A review of the oceanography and renewable resources of the northern Gulf of Alaska. University of Alaska, Institute of Marine Science. Report R72-73, Sea Grant Report 73-3.

Smith, S. B. 1969. Reproductive isolation in summer and winter races of steelhead. Pages 21-38 *in* Northcote, T.C., editor. Symposium of salmon and trout streams, 1968 February 22-24, Vancouver, British Columbia. University of British Columbia, Vancouver, British Columbia.

Smith, C. T., B. F. Koop, and R. J. Nelson. 1998. Isolation and characterization of coho salmon (*Oncorhynchus kisutch*) microsatellites and their use in other salmonids. Molecular Ecology 7:1614-1616.

Spies, I. B., D. J. Brazier, P. T. O'Reilly, T. R. Seamons, and P. Bentzen. 2005. Development and characterization of novel tetra-, tri-, and dinucleotide microsatellite markers in rainbow trout (*Oncorhynchus mykiss*). Molecular Ecology Notes 5: 278-281.

Stephenson, J. J., M. R. Campbell, J.E. Hess, C. Kozfkay, A. P. Matala, M. V. McPhee, P. Moran, S. R. Narum, M. M. Paquin, O. Schlei, M. P. Small, D. M. Van Doornik, and J. K. Wenburg. 2009. A centralized model for creating shared, standardized, microsatellite data that simplifies inter-laboratory collaboration. Conservation Genetics 10:1145–1149. DOI 10.1007/s10592-008-9729-4.

Sumner, F. H. 1948. Age and growth of steelhead trout, Salmo Gairdnerii Richardson, caught by sport and commercial fisherman in Tillamook County, Oregon. Transactions of the American Fisheries Society 75: 77-83.

Tobin, J. H. 1994. Construction and performance of a portable resistance board weir for counting migrating adult salmon in rivers. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office. Alaska Fisheries Technical Report Number 22, Kenai, Alaska.

Walker, R. J., C. Olnes, K. Sundet, A. L. Howe, and A. E. Bingham. 2003. Participation, catch, and harvest in Alaska sport fisheries during 2000. Alaska Department of Fish and Game, Fishery Data Series No. 03-05, Anchorage, Alaska.

Wallis, J. and D. T. Balland. 1982. Anchor River Steelhead Study. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report, 1981-1982, Volume 23, Anadromous Fish Studies-48-2, Juneau, Alaska.

Wallis, J. and D. T. Balland. 1983. Anchor River Steelhead Study. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report, 1982-1983, F-9-16 (25) Anadromous Fish Studies-48-3, Juneau, Alaska.

Wallis, J. and D. T. Balland. 1984. Anchor River Steelhead Study. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report, 1983-1984, F-9-16 (25) Anadromous Fish Studies-48, Juneau, Alaska.

Ward, B. R., and P. A. Slaney. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (Salmo gairdneri) and the relationship to smolt size. Canadian Journal of Fisheries and Aquatic Science 45: 1110-1122.

Weir, B. S. and C. C. Cockerham. 1984. Estimating F-statistics for the analysis of population structure. Evolution 38:1358-1370.

Withler, I. L. 1966. Variability in life history characteristics of steelhead trout (Salmo gairdneri) along the Pacific Coast of North America. Journal of Fisheries Research Board Canada, Volume 23(3): 365-393.

APPENDIX 1. —Harvest and catch estimates of steelhead in the Kasilof River and Crooked Creek between 1986 and 2008. Harvest and catch information was collected by Alaska Department of Fish and Game using the Statewide Harvest Surveys.

Year	Harvest[f]	Catch[f]
1986[a]	92	n/a
1987[a]	185	n/a
1988[a]	36	n/a
1989[a]	48	n/a
1990[a]	145	n/a
1991[a]	12	179
1992[a]	520	1,746
1993[a]	2,237	7,517
1994[b]	1,262	6,156
1995[b]	692	3,835
1996[b]	36	1,320
1997[b]	7	552
1998[b]	0	223
1999[b]	0	764
2000[c]	65	617
2001[d]	26	577
2002[d]	21	983
2003[d]	26	619
2004[d]	0	299
2005[d]	38	954
2006[d]	7	380
2007[e]	8	628
2008[e]	0	506

[a] Mills 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994.
[b] Howe et al. 1995, 1996, 2001a-d.
[c] Walker et al. 2003.
[d] Jennings et al. 2004, 2006 a-b, 2007, 2009 a-b.
[e] Jason Pawluk, Alaska Department of Fish and Game, personal communication.
[f] Harvest and catch include fish from the Kasilof River and Crooked Creek.

APPENDIX 2. —List of video and microwave equipment used to monitor adult steelhead abundance at Crooked and Nikolai creeks between 2004 and 2009.

Item	Model #	Manufacturer	Contact
Digital Video Recorder	DVSM 4-120	Veltek International, Inc.	http://www.veltekcctv.com/
Underwater Camera	Model 10	Applied Micro Video	http://www.appliedmicrovideo.com/
Underwater Lights	Lunaqua 2 12-v	OASE	http://www.pondusa.com
External Harddrive	One Touch 500 GB	Maxtor.com	http://www.maxstore.com
2.4 GHz Microwave Transmitter	BE-530T	Premier Wireless, Inc	http://www.premierwirelessinc.com
2.4 GHz Microwave Receiver	BE-322R	Premier Wireless, Inc	http://www.premierwirelessinc.com
2.4 GHz Parabolic Antennas	130135	California Amplifier	http://www.calamp.com
80 W Solar Module	NE-80EJEA	Sharp	http://solar.sharpusa.com
400 Ah 6 Volt Battery	S-530	Rolls	http://www.rollsbattery.com/
100 Ah 12 Volt Battery	ES27	Exide Technologies	http://www.exide.com/
Charge Controller	ASC8-12	Specialty Concepts, Inc.	http://www.specialtyconcepts.com/
Charge Controller	ASC16-12	Specialty Concepts, Inc.	http://www.specialtyconcepts.com/

APPENDIX 3.—Daily counts and cumulative proportion of adult steelhead observed and estimated passing through the Crooked Creek weir between 2004 and 2009. Boxed areas represent the second and third quartile and median passage dates. Shaded areas are periods when the fish trap was operated for age, sex, and length sampling. Estimated passage is presented in red and only includes years from 2006-2009.

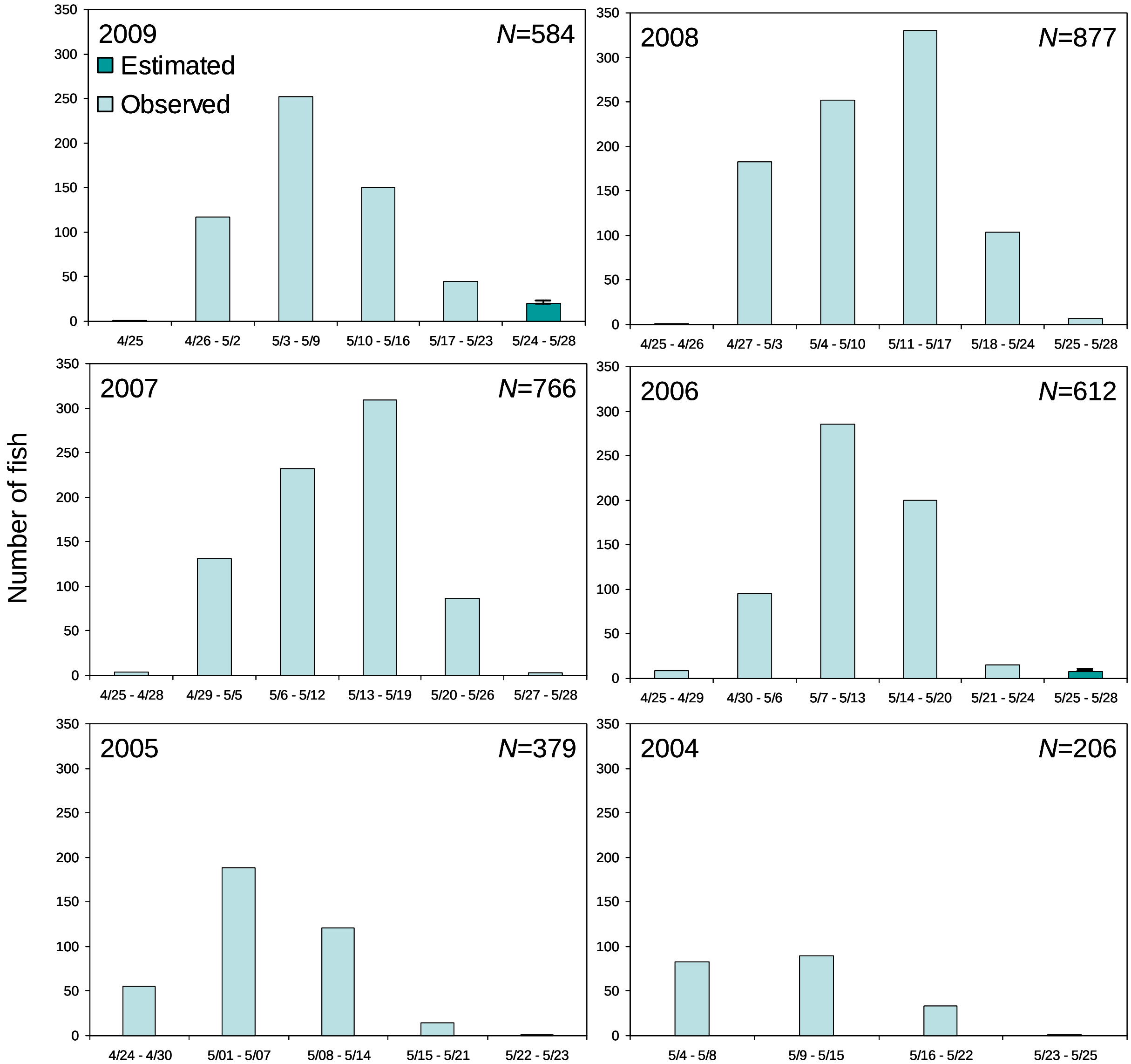
	2004		2005		2006[a]		2007		2008		2009		Estimated
Date	Daily	Cumulative Proportion	Daily	Cumulative Proportion	Daily	Cumulative Proportion	Daily	Cumulative Proportion	Daily	Cumulative Proportion	Daily	Cumulative Proportion	Cumulative Proportion
4/25					0	0.0000	0	0.0000	0	0.0000	1	0.0017	0.0219
4/26					0	0.0000	1	0.0013	1	0.0011	0	0.0017	0.0284
4/27					1	0.0016	1	0.0026	8	0.0103	1	0.0034	0.0367
4/28					1	0.0033	2	0.0052	15	0.0274	0	0.0034	0.0474
4/29			20	0.0528	7	0.0147	2	0.0078	26	0.0570	16	0.0308	0.0609
4/30			35	0.1451	7	0.0261	10	0.0209	21	0.0810	32	0.0856	0.0780
5/1			38	0.2454	2	0.0294	15	0.0405	20	0.1038	43	0.1592	0.0995
5/2			34	0.3351	11	0.0474	19	0.0653	57	0.1688	24	0.2003	0.1260
5/3			32	0.4195	15	0.0719	15	0.0849	36	0.2098	48	0.2825	0.1583
5/4	6	0.0291	19	0.4697	3	0.0768	23	0.1149	15	0.2269	51	0.3699	0.1970
5/5	11	0.0825	25	0.5356	39	0.1405	47	0.1762	61	0.2965	36	0.4315	0.2425
5/6	21	0.1845	16	0.5778	18	0.1699	38	0.2258	3	0.2999	42	0.5034	0.2947
5/7	25	0.3058	24	0.6412	1	0.1716	22	0.2546	28	0.3318	26	0.5479	0.3528
5/8	20	0.4029	42	0.7520	24	0.2108	33	0.2977	21	0.3558	18	0.5788	0.4157
5/9	15	0.4757	24	0.8153	2	0.2141	52	0.3655	53	0.4162	31	0.6318	0.4814
5/10	31	0.6262	27	0.8865	91	0.3627	21	0.3930	71	0.4971	16	0.6592	0.5478
5/11	21	0.7282	18	0.9340	77	0.4886	27	0.4282	44	0.5473	9	0.6747	0.6125
5/12	5	0.7524	0	0.9340	54	0.5768	39	0.4791	100	0.6613	33	0.7312	0.6735
5/13	9	0.7961	6	0.9499	36	0.6356	24	0.5104	39	0.7058	28	0.7791	0.7291
5/14	4	0.8155	4	0.9604	70	0.7500	33	0.5535	29	0.7389	22	0.8168	0.7784
5/15	4	0.8350	2	0.9657	13	0.7712	49	0.6175	19	0.7605	30	0.8682	0.8209
5/16	7	0.8689	2	0.9710	70	0.8856	97	0.7441	67	0.8369	12	0.8887	0.8567
5/17	2	0.8786	4	0.9815	7	0.8971	44	0.8016	32	0.8734	9	0.9041	0.8864
5/18	2	0.8883	1	0.9842	32	0.9493	36	0.8486	20	0.8962	19	0.9366	0.9106
5/19	12	0.9466	3	0.9921	3	0.9542	26	0.8825	46	0.9487	10	0.9538	0.9300
5/20	7	0.9806	1	0.9947	5	0.9624	35	0.9282	21	0.9726	6	0.9640	0.9455
5/21	1	0.9854	1	0.9974	5	0.9706	15	0.9478	4	0.9772	1	0.9658	0.9577
5/22	2	0.9951	0	0.9974	5	0.9788	16	0.9687	4	0.9818	5	0.9743	0.9672
5/23	0	0.9951	1	1.0000	4	0.9853	7	0.9778	4	0.9863	4	0.9812	0.9747
5/24	0	0.9951			1	0.9869	9	0.9896	5	0.9920	3	0.9863	0.9805
5/25	1	1.0000			3	0.9918	3	0.9935	1	0.9932	3	0.9914	0.9850
5/26					2	0.9951	2	0.9961	2	0.9954	2	0.9949	0.9884
5/27					2	0.9984	2	0.9987	2	0.9977	2	0.9983	0.9911
5/28					1	1.0000	1	1.0000	2	1.0000	1	1.0000	0.9932
Total	206		379		612		766		877		584		

[a] Dates between 21 and 24 April were omitted from the table (N=0).

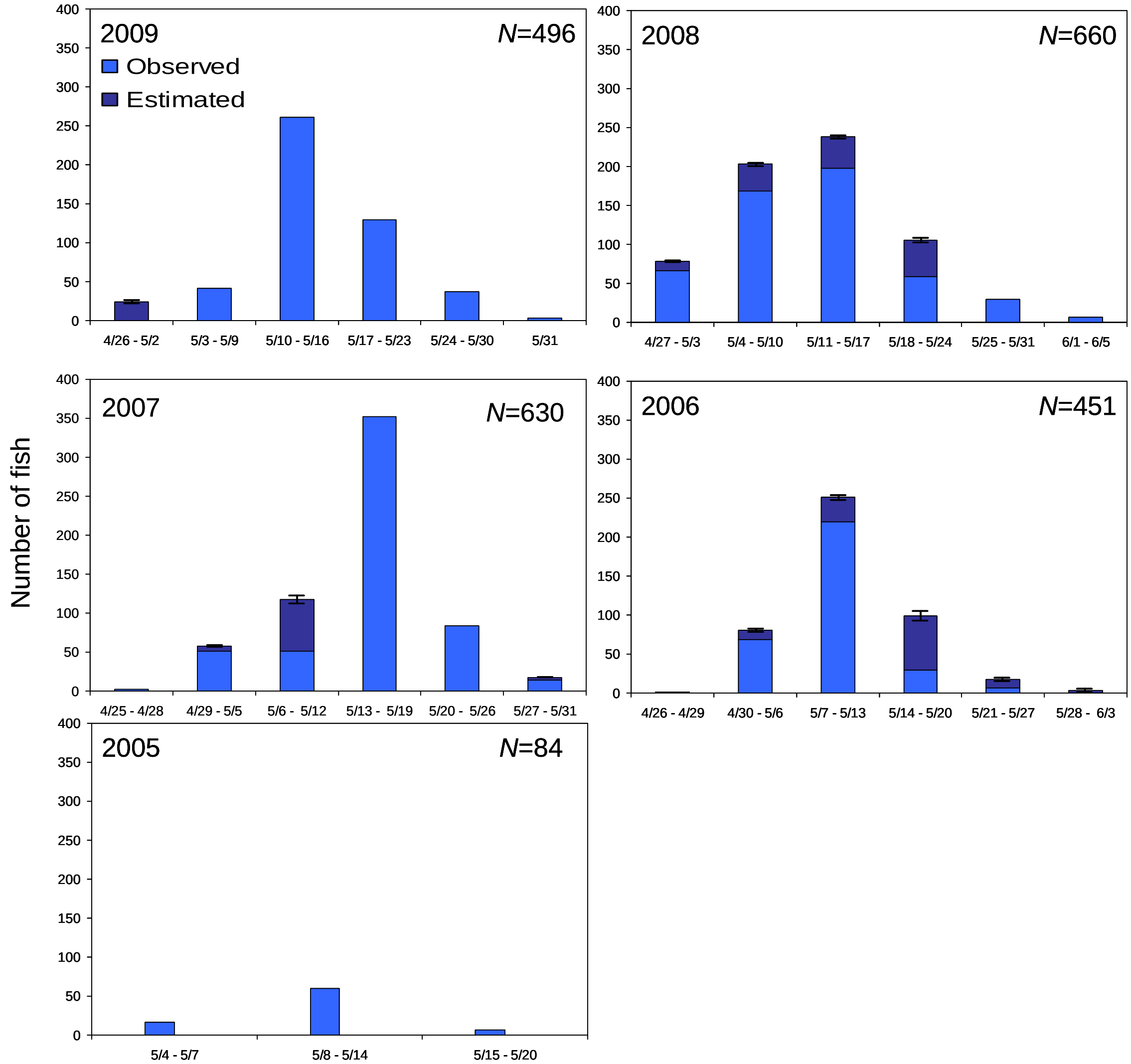
APPENDIX 4. —Daily counts and cumulative proportion of adult steelhead observed and estimated passing through the Nikolai Creek weir between 2005 and 2009. Boxed areas represent the second and third quartile and median passage dates. Shaded areas are periods when the fish trap was operated for age, sex, and length sampling. Estimated passage is presented in red and only includes years from 2006-2009.

	2005		2006		2007		2008		2009		Estimated
Date	Daily	Cumulative Proportion	Daily	Cumulative Proportion	Daily	Cumulative Proportion	Daily	Cumulative Proportion	Daily	Cumulative Proportion	Cumulative Proportion
4/25			0	0.0000	0	0.0000	0	0.0000	0	0.0000	0.0066
4/26			0	0.0000	0	0.0000	0	0.0000	0	0.0000	0.0088
4/27			0	0.0000	1	0.0016	1	0.0015	1	0.0020	0.0119
4/28			1	0.0022	1	0.0032	6	0.0106	2	0.0060	0.0161
4/29			0	0.0022	3	0.0079	3	0.0152	3	0.0121	0.0216
4/30			3	0.0089	19	0.0381	4	0.0212	0	0.0121	0.0290
5/1			3	0.0155	2	0.0413	5	0.0288	5	0.0222	0.0388
5/2			3	0.0222	7	0.0524	26	0.0682	6	0.0343	0.0518
5/3			13	0.0510	7	0.0635	33	0.1182	8	0.0504	0.0688
5/4	3	0.0357	22	0.0998	5	0.0714	59	0.2076	0	0.0504	0.0908
5/5	0	0.0357	24	0.1530	15	0.0952	15	0.2303	1	0.0524	0.1190
5/6	5	0.0952	12	0.1796	10	0.1111	19	0.2591	6	0.0645	0.1545
5/7	8	0.1905	14	0.2106	24	0.1492	13	0.2788	2	0.0685	0.1981
5/8	19	0.4167	17	0.2483	8	0.1619	4	0.2848	13	0.0948	0.2505
5/9	8	0.5119	25	0.3038	11	0.1794	34	0.3364	19	0.1331	0.3113
5/10	2	0.5357	25	0.3592	16	0.2048	59	0.4258	33	0.1996	0.3793
5/11	21	0.7857	48	0.4656	6	0.2143	57	0.5121	47	0.2944	0.4525
5/12	4	0.8333	70	0.6208	42	0.2810	40	0.5727	51	0.3972	0.5278
5/13	0	0.8333	52	0.7361	45	0.3524	13	0.5924	18	0.4335	0.6019
5/14	7	0.9167	23	0.7871	67	0.4587	18	0.6197	46	0.5262	0.6716
5/15	1	0.9286	20	0.8315	60	0.5540	16	0.6439	42	0.6109	0.7344
5/16	1	0.9405	14	0.8625	105	0.7206	49	0.7182	24	0.6593	0.7890
5/17	0	0.9405	15	0.8958	32	0.7714	45	0.7864	39	0.7379	0.8349
5/18	3	0.9762	12	0.9224	18	0.8000	20	0.8167	22	0.7823	0.8725
5/19	0	0.9762	3	0.9290	25	0.8397	16	0.8409	20	0.8226	0.9025
5/20	2	1.0000	12	0.9557	41	0.9048	49	0.9152	10	0.8427	0.9260
5/21			4	0.9645	13	0.9254	10	0.9303	9	0.8609	0.9442
5/22			3	0.9712	14	0.9476	7	0.9409	17	0.8952	0.9581
5/23			3	0.9778	1	0.9492	2	0.9439	12	0.9194	0.9687
5/24			3	0.9845	3	0.9540	1	0.9455	9	0.9375	0.9767
5/25			2	0.9889	8	0.9667	6	0.9545	6	0.9496	0.9826
5/26			1	0.9911	4	0.9730	5	0.9621	9	0.9677	0.9871
5/27			1	0.9933	13	0.9937	5	0.9697	6	0.9798	0.9904
5/28			1	0.9956	1	0.9952	1	0.9712	5	0.9899	0.9929
5/29			1	0.9978	1	0.9968	6	0.9803	2	0.9940	0.9947
5/30			1	1.0000	1	0.9984	2	0.9833	0	0.9940	0.9961
5/31			0	1.0000	1	1.0000	4	0.9894	3	1.0000	0.9971
6/1			0	1.0000	0	1.0000	1	0.9909	0	1.0000	0.9979
6/2			0	1.0000	0	1.0000	3	0.9955	0	1.0000	0.9984
6/3			0	1.0000	0	1.0000	0	0.9955	0	1.0000	0.9988
6/4			0	1.0000	0	1.0000	3	1.0000	0	1.0000	0.9991
6/5			0	1.0000	0	1.0000	0	1.0000	0	1.0000	0.9994
Total	84		451		630		660		496		

APPENDIX 5. —Weekly observed and estimated escapement of adult steelhead in Crooked Creek from 2004 to 2009 including 95% prediction intervals. Counts during the first and last weeks of each year may not include a full week.



APPENDIX 6. —Weekly observed and estimated escapement of adult steelhead in Nikolai Creek from 2005 to 2009 including 95% prediction intervals. Counts during the first and last weeks of each year may not include a full week.



APPENDIX 7. —Length-at-age for adult steelhead sampled at Crooked Creek during 2004, 2005, 2006 and 2008.

2004

Sex	Brood Year[a]	Age[b]	*N*[c]	Mid-Eye to Fork Length Mean	Range	SE
Female	1998	3.2	1	555	–	–
	1997	3.3	1	600	–	–
	1996	4.3	1	665	–	–
	1997	3.2S1	7	641	570 - 705	15.7
	1996	3.2S1S1	7	708	670 - 750	11.3
	Unknown	X.2S1	5	640	625 - 680	10.4
	Unknown	X.2S1S1	2	630	625 - 635	5.0
	Unknown	X.3	5	637	590 - 660	12.2
	Unknown	X.3S1S1	1	635	–	–
Total			30			
Male	1998	3.2	10	531	510 - 570	6.8
	1997	3.3	1	640	–	–
	1997	4.2	2	485	465 - 505	20.0
	1997	3.2S1	1	490	–	–
	Unknown	X.2	6	517	465 - 545	12.0
Total			20			

[a] Brood years could not be determined for fish with incomplete ages (*N* =19).
[b] "X" denotes unreadable freshwater age (*N* =19); "S" denotes spawning event.
[c] Fish with unreadable freshwater and saltwater ages were omitted from this table (*N* =8).

2005

Sex	Brood Year[a]	Age[b]	*N*[c]	Mid-Eye to Fork Length Mean	Range	SE
Female	2000	2.2	2	590	565 - 615	25.0
	1999	3.2	1	620	–	–
	1999	2.2S1	5	623	605 - 660	10.8
	1998	3.3	6	613	560 - 640	12.1
	1998	4.2	1	680	–	–
	1998	3.2S1	20	614	520 - 700	8.9
	1997	3.2S1S1	5	637	600 - 670	14.5
	1996	3.2S1S1S1	1	695	–	–
	Unknown	X.2	1	645	–	–
	Unknown	X.3	4	626	615 - 645	6.6
	Unknown	X.2S1	10	606	540 - 650	10.7
	Unknown	X.2S1S1	1	635	–	–
Total			57			
Male	1999	3.2	3	587	500 - 725	69.9
	Unknown	X.2	3	547	535 - 560	7.3
	Unknown	X.3	1	690	–	–
	Unknown	X.2S1	1	565	–	–
	Unknown	X.2S1S1	1	730	–	–
	Unknown	X.2S1S1S1	1	690	–	–
Total			10			

[a] Brood years could not be determined for fish with incomplete ages (*N* =23).
[b] "X" denotes unreadable freshwater age (*N* =23); "S" denotes spawning event.
[c] Fish with unreadable freshwater and saltwater ages were omitted from this table (*N* =3).

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2006

Sex	Brood Year[a]	Age[b]	*N*[c]	Mid-Eye to Fork Length Mean	Range	SE
Female	2001	2.2	1	605	–	–
	2000	2.3	1	670	–	–
	1999	3.3	7	624	590 - 650	8.4
	1998	4.3	1	685	–	–
	2000	2.2S1	5	632	615 - 650	6.0
	1999	3.1S2	1	650	–	–
	1999	3.2S1	17	618	555 - 675	7.5
	1998	4.2S1	2	630	630 - 630	0.0
	1997	4.2S1S1	1	700	–	–
	1997	4.3S1	1	555	–	–
	Unknown	X.2	5	532	385 - 645	46.5
	Unknown	X.3	9	641	570 - 705	13.5
	Unknown	X.2S1	16	629	580 - 685	6.5
	Unknown	X.2S1S1	3	683	640 - 735	27.7
	Unknown	X.2S1S1S1	1	795	–	–
Total			71			
Male	2001	2.2	1	515	–	–
	2000	3.2	2	508	505 - 510	2.5
	1999	3.3	5	615	575 - 705	21.6
	2000	2.2S1	1	615	–	–
	1999	3.2S1	2	650	645 - 655	5.0
	1998	3.2S1S1	1	690	–	–
	Unknown	X.1S2	1	615	–	–
	Unknown	X.2	2	520	515 - 525	5.0
	Unknown	X.3	7	621	550 - 695	17.9
	Unknown	X.2S1	4	624	520 - 670	35.0
	Unknown	X.3S1S1S1	1	700	–	–
Total			27			

[a] Brood years could not be determined for fish with incomplete ages (*N* =49).
[b] "X" denotes unreadable freshwater age (*N* =49); "S" denotes spawning event.
[c] Fish with unreadable freshwater and saltwater ages were omitted from this table (*N* =20).

2008

Sex	Brood Year[a]	Age[b]	*N*[c]	Mid-Eye to Fork Length Mean	Range	SE
Female	2001	3.3	5	638	585 - 680	19.1
	2001	4.2	1	590	–	–
	2000	3.3S1	3	577	500 - 620	38.4
	1999	4.3S1	2	473	660 - 685	12.5
	Unknown	X.2	5	602	510 - 680	30.3
	Unknown	X.3	5	665	635 - 705	12.3
	Unknown	X.2S1S1	2	688	670 - 705	17.5
	Unknown	X.3S1	4	650	575 - 720	31.7
	Unknown	X.2S1S1S1	1	705	–	–
	Unknown	X.2S1S1S1S1	1	710	–	–
Total			29			
Male	2001	3.3	1	705	–	–
	2001	3.2S1	1	520	–	–
	2000	4.2S1	2	650	610 - 690	40.0
	1999	4.3S1	1	700	–	–
	Unknown	X.2S1	2	525	500 - 550	25.0
	Unknown	X.3	1	590	–	–
	Unknown	X.3S1	3	697	685 - 715	9.3
Total			11			

[a] Brood years could not be determined for fish with incomplete ages (*N* =25).
[b] "X" denotes unreadable freshwater age (*N* =25); "S" denotes spawning event.
[c] Fish with unreadable freshwater and saltwater ages were omitted from this table (*N* =10).

APPENDIX 8. —Length-at-age for adult steelhead sampled at Nikolai Creek during 2008 and 2009.

2008

Sex	Brood Year[a]	Age[b]	N [c]	Mid-Eye to Fork Length Mean	Range	SE
Female	2002	3.2	1	665	–	–
	2001	3.3	3	652	630 - 695	21.7
	2001	4.2	1	630	–	–
	2000	4.3	2	673	670 - 675	2.5
	2001	3.2S1	2	510	475 - 545	35.0
	2000	3.3S1	2	668	645 - 690	22.5
	1999	3.3S1S1	1	815	–	–
	2000	4.2S1	1	700	–	–
	1999	4.3S1	3	667	645 - 680	10.9
	Unknown	X.2	2	578	490 - 665	87.5
	Unknown	X.3	1	665	–	–
	Unknown	X.4	2	700	690 - 710	10.0
	Unknown	X.2S1	1	610	–	–
	Unknown	X.3S1	10	655	620 - 735	9.5
	Unknown	X.3S1S1	1	720	–	–
Total			33			
Male	2001	3.3	1	770	–	–
	2001	3.2S1	4	646	560 - 700	31.5
	2000	3.3S1	1	700	–	–
	2000	4.2S1	4	558	525 - 600	19.2
	1999	4.3S1	1	650	–	–
	1999	5.2S1	1	585	–	–
	Unknown	X.2	1	740	–	–
	Unknown	X.3	1	755	–	–
	Unknown	X.2S1	6	601	510 - 785	47.0
	Unknown	X.3S1	2	730	705 - 755	25.0
Total			22			

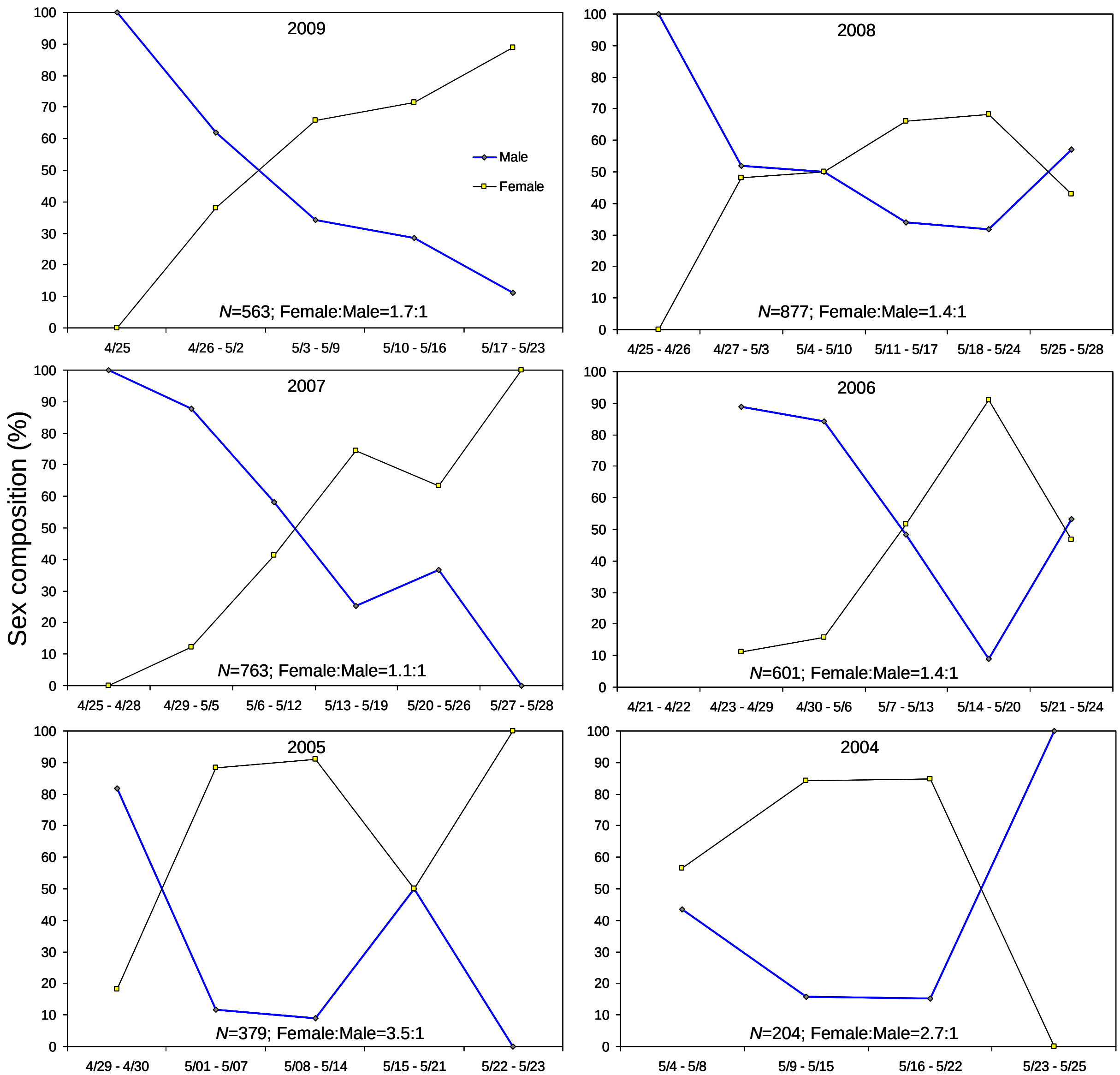
[a] Brood years could not be determined for fish with incomplete ages (*N* =27).
[b] "X" denotes unreadable freshwater age (*N* =27); "S" denotes spawning event.
[c] Fish with unreadable freshwater and saltwater ages were omitted from this table (*N* =11).

2009

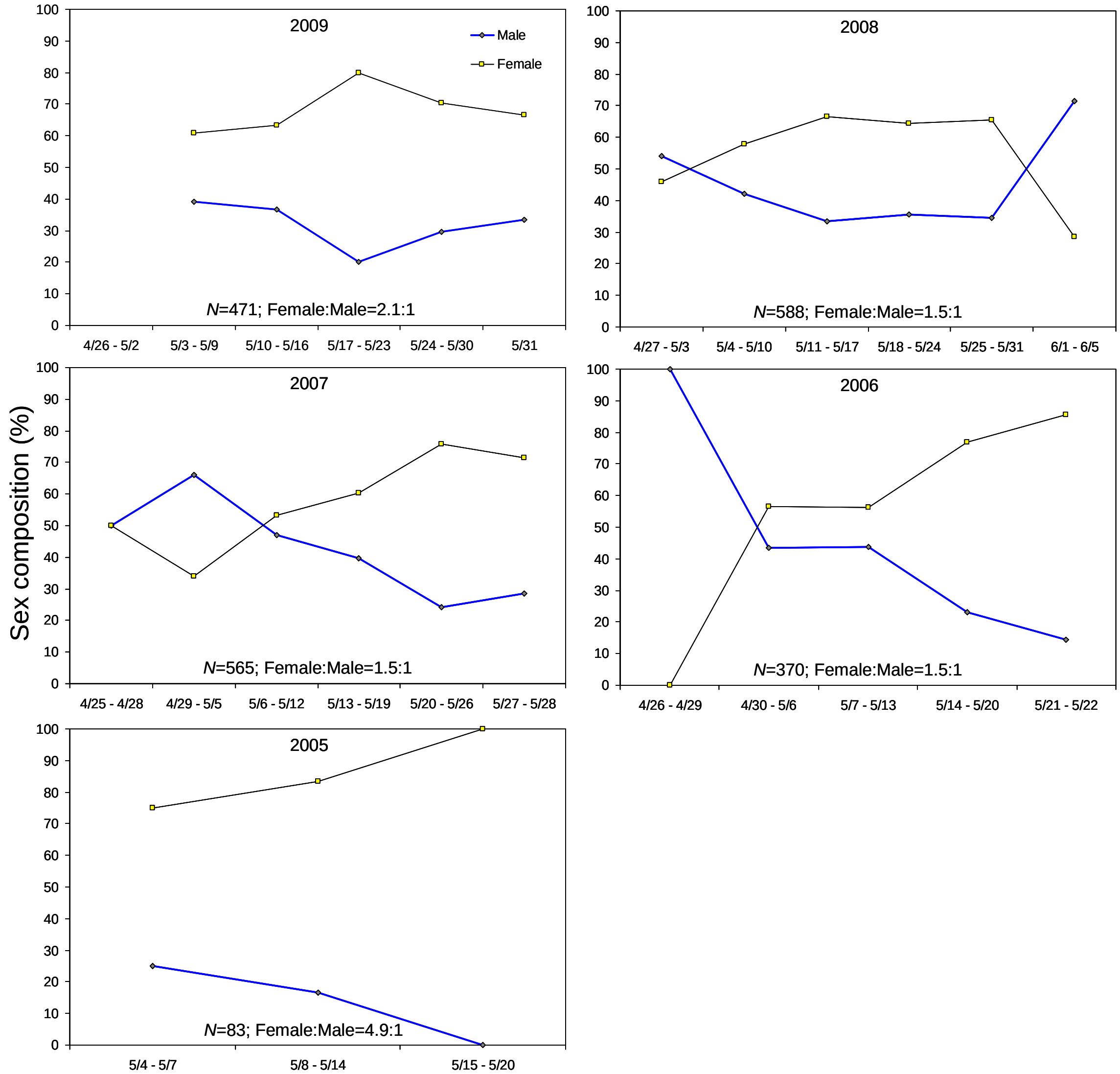
Sex	Brood Year[a]	Age[b]	N [c]	Mid-Eye to Fork Length Mean	Range	SE
Female	2000	3.3	1	740	–	–
	2000	4.2	1	605	–	–
	1999	4.3	2	678	675 - 680	2.5
	1999	3.3S1	1	650	–	–
	1999	4.2S1	2	653	640 - 665	12.5
	1998	4.3S1	7	629	590 - 685	11.5
	1998	5.2S1	1	660	–	–
	Unknown	X.2	1	470	–	–
	Unknown	X.3	2	645	610 - 680	35.0
	Unknown	X.2S1	1	695	–	–
	Unknown	X.3S1	6	659	630 - 715	13.1
	Unknown	X.2S2S1	1	725	–	–
	Unknown	X.2S1S1S1	1	740	–	–
Total			27			
Male	2000	3.3	1	610	–	–
	1999	3.3S1	1	645	–	–
	1999	3.2S1S1	1	725	–	–
	1999	4.2S1	1	535	–	–
	Unknown	X.2S1	3	640	545 - 745	58.0
	Unknown	X.2S2	1	715	–	–
	Unknown	X.3S1	4	698	625 - 755	32.6
	Unknown	X.2S1S1	1	675	–	–
Total			13			

[a] Brood years could not be determined for fish with incomplete ages (*N* =21).
[b] "X" denotes unreadable freshwater age (*N* =21); "S" denotes spawning event.
[c] Fish with unreadable freshwater and saltwater ages were omitted from this table (*N* =3).

APPENDIX 9. —Weekly percent of male and female adult steelhead observed at Crooked Creek from 2004 to 2009. Counts during the first and last weeks of each year do not include a full week. Steelhead with unknown sex were not included in the analysis (2009, *N*=1; 2007, *N*=3; 2006, *N*=3).



APPENDIX 10. —Weekly percent of male and female adult steelhead observed at Nikolai Creek from 2005 to 2009. Counts during the first and last weeks of each year do not include a full week. Steelhead with unknown sex were not included in the analysis (2007, *N*=4; 2006, *N*=3; 2005, *N*=1).



APPENDIX 11. —Mean daily water temperatures for Crooked and Nikolai creeks from 2004 to 2009.

	Crooked Creek						Nikolai Creek				
Date	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2005**	**2006**	**2007**	**2008**	**2009**
4/15	0.76	0.57	0.00				0.38	0.45	0.06	0.16	
4/16	0.86	1.55	0.00				0.78	0.29	0.06	0.37	
4/17	0.89	1.82	0.00				1.18	1.07	0.06	0.66	
4/18	1.44	2.02	0.14	0.05			1.67	1.38	0.06	1.14	
4/19	1.51	2.29	0.88	0.14			1.61	1.15	0.06	1.19	
4/20	1.80	2.19	1.15	0.17			1.25	1.14	0.06	1.02	
4/21	2.41	2.85	1.29	0.15			1.12	1.63	0.07	0.90	
4/22	3.10	2.05	1.09	0.16			1.51	1.03	0.16	0.62	
4/23	3.06	1.87	1.31	0.53		0.06	0.74	1.10	0.49	0.92	
4/24	2.83	3.60	1.25	0.49		0.29	1.42	0.81	0.53	0.99	
4/25	3.37	5.08	1.17	1.12	0.56	0.67	2.04	0.96	0.62	0.48	
4/26	4.30	6.09	1.54	2.45	0.73	2.01	2.58	1.68	1.12	0.40	0.61
4/27	3.46	6.83	1.92	2.76	1.85	2.07	3.35	1.55	1.32	1.26	0.74
4/28	3.16	7.00	2.09	2.65	2.17	2.55	3.35	1.70	1.22	1.45	1.52
4/29	3.94	7.10	2.00	2.87	2.37	3.10	3.05	1.40	1.35	1.32	1.78
4/30	4.39	7.73	2.32	3.04	2.38	4.02	3.43	1.56	1.60	1.38	2.35
5/1	5.56	7.11	2.39	3.13	2.24	4.57	3.73	1.58	1.56	1.22	2.95
5/2	6.01	6.95	2.24	2.95	2.91	4.85	3.71	1.63	2.08	1.83	3.52
5/3	5.85	6.59	2.31	3.73	2.95	5.32	3.62	1.45	2.40	1.75	3.88
5/4	7.43	5.90	2.45	4.80	2.75	5.95	4.10	1.72	2.44	1.57	4.33
5/5	8.09	6.10	2.57	5.00	3.34	5.84	3.29	1.88	2.47	2.27	4.45
5/6	8.93	7.81	2.83	4.63	3.03	5.07	4.27	1.81	2.34	2.12	3.73
5/7	9.51	8.80	2.53	4.67	3.35	4.73	5.90	1.42	2.19	2.14	4.37
5/8	8.75	9.39	2.44	5.06	3.79	5.90	6.38	1.63	2.58	1.89	5.09
5/9	7.46	9.92	2.66	4.98	4.10	6.77	6.99	1.88	2.60	2.81	5.64
5/10	7.90	10.04	3.06	4.41	4.74	6.91	7.41	2.58	2.30	2.70	5.87
5/11	8.29	10.10	4.27	5.06	4.72	7.59	7.30	3.26	2.67	2.82	6.79
5/12	8.24	8.89	5.07	4.95	4.76	8.47	7.92	3.56	2.80	3.06	7.70
5/13	9.14	8.47	5.63	4.61	4.14	8.82	7.09	3.38	3.13	2.61	7.80
5/14	8.58	7.99	5.73	5.24	4.04	8.73	7.43	3.05	3.34	2.58	7.77
5/15	7.02	8.33	5.85	6.10	4.57	7.62	7.14	3.17	4.17	3.15	5.94
5/16	6.41	9.18	6.22	6.98	5.38	6.75	7.55	3.40	3.72	3.34	6.39
5/17	6.11	8.97	5.79	6.66	5.73	7.88	7.76	3.35	3.75	3.41	7.26
5/18	7.18	9.71	6.18	6.84	6.64	8.84	7.45	3.17	3.67	3.28	7.97
5/19	8.61	10.75	5.64	6.94	6.90	8.67	8.20	3.36	4.28	3.68	7.46
5/20	9.86	10.08	5.58	7.78	7.31	7.92	8.91	3.17	4.58	4.29	7.06
5/21	10.74	10.13	6.05	8.11	8.19	7.61	8.59	3.82	4.89	4.48	6.72
5/22	11.78	10.28	8.06	7.96	8.33	7.68	8.37	4.69	4.58	4.18	7.02
5/23	11.00	10.05	9.39	6.03	8.09	7.38	8.32	4.85	4.15	4.65	6.45
5/24	9.11	10.71	10.16	6.50	7.48	7.47	8.47	5.16	4.93	3.23	6.36
5/25	8.78	10.85	10.46	6.92	6.36	8.01	9.63	6.05	4.86	3.49	7.90
5/26	9.05	10.22	11.00	6.29	7.43	10.05	9.40	7.10	4.93	4.57	9.72
5/27	9.10	10.07	11.24	7.06	8.66	9.70	8.91	8.24	5.62	5.22	8.76
5/28	8.21	10.33	11.47	6.98	9.44	7.67	9.29	8.67	5.70	5.55	6.75
5/29	8.93	9.86	11.17	8.72	9.37	7.19	9.51	9.20	5.00	5.40	6.84
5/30	10.37	10.26	11.09	10.41	9.43	7.06	9.03	9.33	6.45	5.70	6.56
5/31	9.86	9.76	9.69	10.41	9.72	7.67	8.77	7.74		6.05	7.63
6/1										5.30	7.87
6/2										4.97	8.23
6/3										5.37	9.71
6/4										5.70	9.65
6/5										5.15	8.93