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Jeffry L. Anderson and Stillwater Sciences

Abstract

Existing aquatic habitat inventory data and assessments throughout Alaska are incomplete. This limits the ability of resource managers to understand, anticipate, and prepare appropriate responses to changes in watershed processes that can result from anthropogenic impacts and climate change. To address this need, the Kenai Fish and Wildlife Field Office and Stillwater Sciences implemented a habitat assessment project on the Anchor River watershed in Southcentral Alaska. The goals of the project were to assess current habitat conditions for Chinook *Oncorhynchus tshawytscha* and Coho *O. kisutch* salmon in the Anchor River watershed, to increase our understanding of the relationships of key life stages of salmon to these habitats throughout the watershed, and to model the potential responses of Chinook and Coho salmon populations to restoration efforts and potential shifts resulting from climate change using a predictive model (RIPPLE). This report presents field investigations conducted in 2011 to parameterize and validate the application of the RIPPLE model in the Anchor River watershed including: 1) estimating abundance and migration timing of Chinook and Coho salmon smolts using a rotary-screw trap; 2) estimating abundance of adult Coho Salmon using an underwater video system at a weir; and 3) estimating juvenile salmonid densities in the watershed using depletion/removal methods. An estimated 203,775 Chinook (90% confidence interval (C.I.): 137,673 to 269,877) and 56,030 Coho salmon smolts (90% C.I.: 47,302 to 64,758) migrated from the Anchor River from May through July 2011. Low water levels created challenges for operating the screw trap in 2011 in contrast to high water events that hindered operations in 2010. A total of 1,866 adult Coho Salmon were counted passing the Anchor River weir between July 27 and September 21, 2011, the lowest number of Coho Salmon counted since weir monitoring began in 2004. We estimated a 2.9% smolt-to-returning adult survival rate for Anchor River Coho Salmon using a corrected estimate of smolt abundance in 2010 and observed weir adult escapement in 2011. Overall capture numbers and observed densities for juvenile Chinook and Coho salmon were higher in 2011 than 2010.

Introduction

Existing aquatic habitat inventory data and assessments throughout Alaska are incomplete. This limits the ability of resource managers to understand, anticipate, and prepare appropriate responses to changes in watershed processes that can result from anthropogenic impacts and climate change. Global circulation models predict air temperature increases of between 7.2°C and 8.5°C for the Cook Inlet Basin and 20% to 25% increases in precipitation by 2100 and temperature changes will be greater in the winter months (Kyle and Brabets 2001). Water temperatures in Kenai Peninsula streams that drain lowland areas typically have higher temperatures than watersheds that include glaciers, and some lowland streams are predicted to experience increases in water temperature of over 5°C (Kyle and Brabets 2001). These high

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stream temperatures could result in reduced survival of salmon eggs and fry, reduced growth rates due to increased rates of respiration and metabolism, premature smolting and shifts in emigration timing that reduce marine survival, greater vulnerability to pollution due to increased toxicity of some organic chemicals and metals, and greater risk of predation and disease (Richter and Kolmes 2005). Cumulative effects of increasing water temperatures may also lead to changes in life history strategies for some salmonids (Bryant 2009), some of which may be beneficial depending on the amount of temperature change. However, changes that result in the loss of life history diversity will make populations less viable (Mobrand et al. 1997).

The Kenai Fish and Wildlife Field Office (KFWFO) partnered with Stillwater Sciences to implement a habitat assessment project on the Anchor River watershed using a predictive life-cycle model called RIPPLE (Software Interface: © 2008, University of California, Berkeley; Software Program: © 2008, Stillwater Ecosystem, Watershed & Riverine Sciences). The RIPPLE (not an acronym) model characterizes geomorphic and ecological processes that create and maintain freshwater salmon habitat, predicts the distribution of fish habitat conditions, and simulates salmon population dynamics (Stillwater Sciences 2009). The goals of the project are to assess current habitat conditions for Chinook *Oncorhynchus tshawytscha* and Coho *O. kisutch* salmon in the Anchor River watershed, to increase the understanding of the relationship of key life stages of salmon to these habitats throughout the watershed, and to model the potential responses of Chinook and Coho salmon populations to restoration efforts and potential shifts resulting from climate change. Specifically, Stillwater Sciences is working to characterize salmon habitats in the Anchor River through application and field-calibration of RIPPLE, compare the model results to the *Catalog of Waters Important for the Spawning, Rearing or Migration of Anadromous Fishes* (Johnson and Klein 2009) and other data, use RIPPLE to predict population potential for Chinook and Coho salmon, and consider potential effects of climate change on Anchor River salmon populations including elevated stream temperatures and altered flow and sediment regimes.

The KFWFO conducted field investigations from May 2010 to July 2012 to parameterize and validate the application of the RIPPLE model in the Anchor River watershed through the following objectives:

1. To estimate numbers of Chinook and Coho salmon smolts emigrating from the Anchor River watershed such that estimates are within 25% of the true value 90% of the time;
2. To estimate the weekly age and size composition of Chinook and Coho salmon smolts in Anchor River such that simultaneous 90% confidence intervals (C.I.) have a maximum width of 0.20;
3. To estimate Chinook and Coho salmon overwinter survival such that the estimate is within 20% of the actual value 90% of the time;
4. To estimate Coho Salmon smolt-to-spawning adult return rate in the Anchor River such that the estimate is within 25% of the true value 90% of the time;
5. To estimate the habitat type-specific mean density of juvenile Chinook and Coho salmon such that 90% C.I. have maximum width of 25%;
6. To estimate habitat type-specific size and age composition of juvenile Chinook and Coho salmon such that simultaneous 90% C.I. estimates of the age composition have a maximum width of 0.20;

7. To count the number of adult Coho Salmon passing the weir in the Anchor River from late July through October.

This report summarizes field work conducted during 2011, and results from 2010 are reported in Anderson and Stillwater Sciences (2011). Results from Objective 3 will be presented as part of a Master of Science thesis through West Virginia University, and overall RIPPLE model analysis and predictions will be reported through separate documents.

Study Area

The Anchor River watershed (Figure 1) drains about 580 km^2 of the lower Kenai Peninsula in Southcentral Alaska (Mauger 2005). The watershed is non-glacial. The North and South forks of the Anchor River join to form a 5th order river about 3 km upstream from Cook Inlet, and the lower 2 km are influenced by tidal flows. The South Fork watershed is about twice the size of the North Fork watershed. Climate is characterized as a transitional zone between the maritime and continental zones and averages about 76 cm of precipitation that generally falls as snow between November and March (Kyle and Brabets 2001). Peak streamflows generally occur in April and May as snowmelt runoff, although rain events can cause large peaks in discharge during summer and fall in some years (U.S. Geological Survey, unpublished data: http://waterdata.usgs.gov/nwis/nwisman/?site_no=15239900). For example, two significant flood events occurred during fall 2002 that caused heavy erosion, channelization, and damage to bridges and culverts. These events were caused by heavy rains and were in excess of any known or recorded flow event in the last 100 years (Szarzi et al. 2007).

Human activity is prevalent in the watershed and includes residential land use, gravel mining, logging, and recreation. Much of the lower watershed is accessible via roads, and numerous all-terrain vehicle trails and trails established during seismic surveys provide access to the upper watershed. A spruce bark beetle outbreak in the 1990s killed off a large percentage of the spruce trees in the watershed which makes the area vulnerable to wildfire (Ross et al. 2001). Public lands comprise about half (51%) of the watershed and almost half of the watershed (48%) has been classified as wetlands (Mauger 2005).

Five species of Pacific salmon, steelhead *O. mykiss* (anadromous Rainbow Trout), and Dolly Varden *Salvelinus malma* have been documented in the Anchor River (Johnson and Klein 2009), although the watershed supports few Chum *O. keta*, Pink *O. gorbuscha*, or Sockeye *O. nerka* salmon. Chinook Salmon escapement in the watershed has ranged from 3,504 to 12,016 from 2003 to 2010, and Coho Salmon escapement has ranged from 2,691 to 18,977 from 2004 to 2010 (Table 1). The South Fork supports about 84% of the Chinook and 88% of the Coho salmon escapement (Kerkvliet et al. 2008). Chinook Salmon, Coho Salmon, steelhead, and Dolly Varden support large and popular sport fisheries on the Anchor River (Szarzi et al. 2007). Other native species in the watershed include Rainbow Trout, Threespine Stickleback *Gasterosteus aculeatus* and sculpin *Cottus* spp. Anderson and Stillwater Sciences (2011) also report captures of Lamprey *Lampetra* spp. and Eulachon *Thaleichthys pacificus* in a rotary-screw trap. Except for some juvenile steelhead that were obviously smolts, we could not distinguish between juvenile Rainbow Trout and juvenile steelhead. Therefore, juveniles of both life history forms are referred to as juvenile *O. mykiss* throughout the remainder of the report.

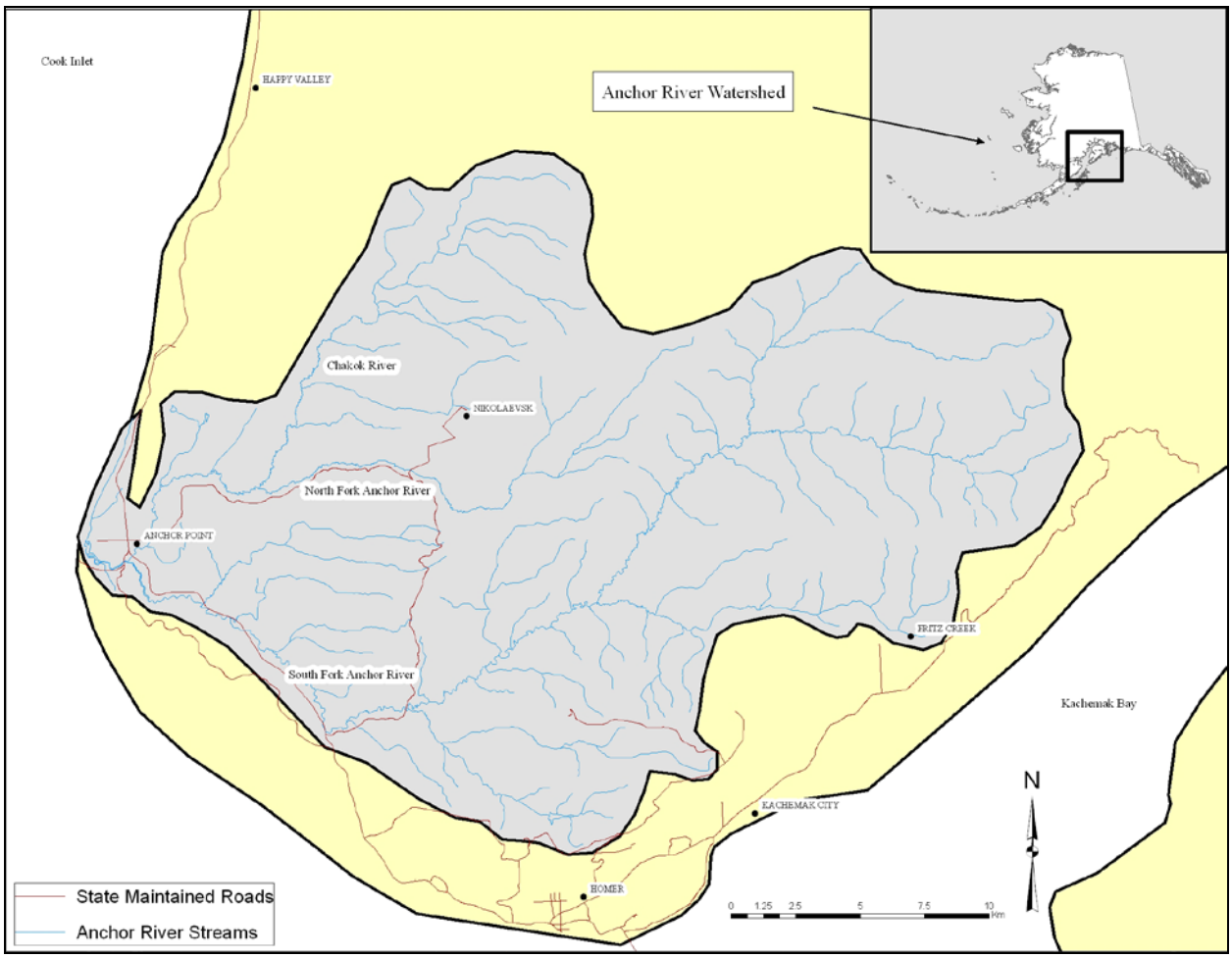

Figure 1. Map of the southern Kenai Peninsula, Alaska, showing locations of major roads, communities, and location of the Anchor River watershed.

Table 1. Chinook and Coho salmon escapement estimates in the Anchor River, 2003 to 2010.

Year	Chinook Salmon	Coho Salmon
2003[a]	9,238	
2004[a]	12,016	5,728
2005[a]	11,095	18,977
2006[a]	8,945	10,181
2007[a]	9,634	8,227
2008[b]	5,806	5,951
2009[b]	3,455	2,692
2010	3,530[c]	6,014[d]

[a] Szarzi et al. (2007).
[b] Kerkvliet and Booz (2012).
[c] ADF&G, unpublished data.
[d] Anderson and Stillwater Sciences (2011).

Methods

We used a rotary-screw trap to monitor the migration of Chinook and Coho salmon smolts throughout the run. Smolt abundance (Objective 1) was assessed using mark-recapture techniques at the trap, and age and size composition (Objective 2) were described by sampling outmigrating smolts throughout the run. The Coho Salmon smolt estimate from 2010 was used with the observed adult return in 2011 to estimate smolt-to-spawning adult return rate for Coho Salmon (Objective 4). We used electrofishing, minnow traps, and seines for depletion-removal experiments to estimate habitat-type specific mean densities of juvenile Chinook and Coho salmon in the Anchor River watershed (Objective 5) and we sampled those fish to estimate their size and age composition (Objective 6). We used a weir in conjunction with an underwater video system to count adult Coho Salmon returning to the Anchor River during August and September (Objective 7). For all objectives, the length of juvenile fish was measured to fork length (FL in mm).

Smolt Outmigration

We used a single rotary-screw trap to estimate Chinook and Coho salmon smolt abundance by marking and releasing fish on a daily basis and using recapture data to estimate trap efficiency. Our sampling was stratified weekly (Sunday through Saturday). A sample of each fish species captured at the trap each day were marked and released above the trap each evening at the confluence of the North and South forks. Any marked fish recaptured at the screw trap following their release were used to estimate trap efficiency and smolt abundance.

Fish Capture and Handling —We used a rotary-screw trap to capture outmigrating smolts in the main-stem Anchor River from May 18 through July 23, 2011. Rotary-screw traps are a common capture technique used successfully to estimate population size, migration timing, survival rates, and other characteristics of migrating juvenile salmonids and other fishes (Kennen et al. 1994;

Thedinga et al. 1994; Roper and Scarnecchia 1999; Miller and Sadro 2003; Eskelin 2004; Downs et al. 2006; Feyrer et al. 2006; Venditti et al. 2006; Volkhardt et al. 2007; Sykes et al. 2009). The trap consisted of a revolving stainless-steel, 2-mm-mesh cone on aluminum pontoons that was located downstream of the confluence of the North and South forks near the Old Sterling Highway Bridge. The cone entrance diameter was 2.4 m and about half of the entrance area (about 2.2 m^2) was submerged. Stream flow caused the trap cone to rotate and fish passing through the cone were collected in a live well located at the downstream end of the trap. The trap was secured to shore, placed in the thalweg to maximize capture efficiency, and was checked at least three times daily between 0700 and 2200 hours. When high water or debris caused concerns or when unusually high numbers of juveniles were passing, we checked the trap more frequently throughout the day and night.

All fish captured at the screw trap were identified to species and counted. Chinook and Coho salmon were classified as either smolt, parr, or transitional based on the presence or absence of parr marks and skin coloration as per Ewing et al. (1984) and Viola and Shuck (1995). Fish that were silver in coloration and had faint or non-existent parr marks were classified as smolts, fish that were dark in coloration and had distinct parr marks were classified as parr, and fish with characteristics of both smolt and parr (silver in coloration with distinct parr marks) were classified as transitional. Another characteristic used to distinguish smolts from parr and presmolts was the darkening of fin tips (Thedinga et al. 1994) or fin margin blackening (Wedemeyer et al. 1980). All Chinook and Coho salmon captured at the trap were also examined for marks and visual implant elastomer tags, and scanned for the presence of passive integrated transponder (PIT) tags (as part of Objective 3) using a Biomark® FS2001F-ISO portable reader and loop antenna. All other non-marked and non-target fish captured in the smolt trap were identified to species and life stage (for salmonids), counted, placed in a live well, allowed to recover, and released once fish had recovered from handling. We noted any fish mortalities and excluded them from the count.

To estimate trap efficiency, up to 45 Chinook and 45 Coho salmon classified as smolt or transitional each day were measured for length, and alternately marked by strata (see Table 2) using surgical scissors cleaned with alcohol and placed in 12-L buckets. Once sample size goals were obtained, marked fish were transferred from buckets to a live well near the release site and allowed to recover. Recovery time in the live well was usually about 8 to 10 hours, and all marked fish were released near dusk or by 2300 hours at the confluence of the North and South forks, about 100 m upstream of the screw trap. Any fish mortalities observed in the live well were noted prior to release of the marked fish.

Scale samples were collected from a sub-sample of captured fish that were not part of the trap efficiency trials, with a daily maximum goal of 11 Chinook and 11 Coho salmon classified as smolt or transitional. This sample size goal was established such that simultaneous 90% C.I. estimates of the age composition for each species in each week would have a maximum width of 0.20 based on two age categories (Bromaghin 1993), which allowed for an estimated 15% unreadable scales. Fish selected for scale sample collection were anesthetized using a buffered tricaine methanesulfonate (MS-222) solution at a concentration of 40 mg/L (Schoettger and Julin 1967) with a target induction time of one to three minutes (CBFWA 1999) and measured for length. Scale “smears” were collected from the preferred area as described by Jearld (1983), but only from the right side of the fish to minimize problems when scales are removed from the left side of returning adults. Scale samples were placed in individual coin envelopes and labeled

Table 2. Stratum dates and partial caudal fin clips (top or bottom lobe) for Chinook and Coho salmon smolts used to estimate trap efficiency.

Strata	Dates	Mark
1	May 18 - 28	Top lobe
2	May 29 – June 4	Bottom lobe
3	June 5 – 11	Top lobe
4	June 12 – 18	Bottom lobe
5	June 19 – 25	Top lobe
6	June 26 – July 2	Bottom lobe
7	July 3 – 9	Top lobe
8	July 10 – 16	Bottom lobe
9	July17 – 23	Top lobe

with capture date, crew, capture method, location, species, length, and smolt stage. Scales were aged following the guidelines of Mosher (1968), and juvenile ages are reported based on the number of winters the fish spent in fresh water followed by a plus sign (e.g., age 1+). Sampled fish were allowed to recover in a live well prior to release. We did not collect scale samples from fish marked as part of the trap efficiency experiment to minimize handling effects for those fish.

Data Analysis —Chinook and Coho salmon smolt abundance was estimated using a modification of a stratified mark-recapture design based on the recapture of marked smolts and trap efficiencies described by Carlson et al. (1998) using their equations and notations (below). Our main modification was to mark and release smolts each day during weekly strata instead of only marking and releasing fish once per stratum. Since recapture rates were low in some strata, we used DARR (Darroch Analysis with Rank Reduction; Bjorkstedt 2005), version 2.02 (Bjorkstedt 2010), to inform pooling of strata. For each stratum *h*, the smolt population size excluding marked releases and observed mortality ($\hat{U}_h$) was estimated as

$$\hat{U}_h = \frac{u_h(M_h + 1)}{m_h + 1},$$

where u_h is the number of unmarked smolts captured in *h*, M_h is the number of marked smolts released in stratum *h*, and m_h is the number of marked smolts recaptured in *h*. An unbiased estimate of the variance of $\hat{U}_h$ was calculated as

$$v(\hat{U}_h) = \frac{(M_h + 1)(u_h + m_h + 1)(M_h - m_h)u_h}{(m_h + 1)^2(m_h + 2)}.$$

Total smolt abundance ($\hat{U}$) was estimated as

$$\hat{U} = \sum_{h=1}^{L} \hat{U}_h ,$$

where L is the number of strata, and the variance estimate was calculated as

$$v\left(\hat{U}\right) = \sum_{h=1}^{L} v\left(\hat{U}_h\right).$$

An approximate 90% C.I. was calculated as

$$\hat{U} \pm 1.645\sqrt{v\left(\hat{U}\right)}.$$

We set our goal for M_h at 300 fish of each species based on Equation 22 of Carlson et al. (1998) with assumptions of a 15% trap efficiency, a relative error of 25%, and $\alpha = 0.10$. Marking and releasing 45 fish each day allowed us to achieve this goal during most weekly strata. We assumed that fish marked in a given temporal stratum were recaptured within the same stratum, as has been observed by many researchers (Thedinga et al. 1994; Roper and Scarnecchia 1996; Roper and Scarnecchia 1999; Eskelin 2004; Steinhorst et al. 2004). However, we applied two alternating marks over the course of the season (Table 2) to investigate this assumption. Only fish classified as smolt or transitional were marked.

We estimated short-term mark survival for Chinook Salmon on two occasions using techniques described by Thedinga et al. (1994). We held a sample of 25 marked and 25 unmarked smolts in a live well for one day and counted remaining marked and unmarked live fish. Short-term mark survival (S) was estimated as

$$S = \frac{a}{A},$$

where a is the remaining number of marked live fish and A is the initial number of marked smolts held. Survival on both occasions was 100% for all fish so no modifications of M_h were necessary.

Assumptions associated with each stratum for the above methods are (Carlson et al. 1998): 1) closed population; 2) all smolts have the same probability of being marked or all smolts have the same probability of being examined for marks; 3) constant capture probability; 4) marks are not lost between release and recovery; 5) all marked smolts are reported; and 6) all marked smolts released are either recovered or pass by the downstream capture site. Basic data summaries, scatter plots, and statistical analyses were used to describe characteristics of captured smolts and to investigate the validity of assumptions. Assumption 1 was probably met in most strata, and mortality observed during handling and marking was minimal and was censored from the estimate. Assumption 2 involves potential problems associated with random sampling, mixing of marked and unmarked smolts, and variable catchability based on size selectivity, marking effects, or other factors. We addressed this assumption by randomly netting our daily marking sample from the live well when possible. At times, it was necessary to mark all fish captured in the live well to achieve daily sample size goals. Also, we selected a release site at the confluence of the North and South forks about 100 m upstream of the trap to maximize the probability that marked fish were able to mix with the general population prior to recapture (Seelbach et al. 1985; Thedinga et al. 1994). We also investigated size selectivity by comparing lengths of

marked and recaptured fish using a Kolmogorov-Smirnov two-sample test that compares the largest unsigned difference (D) to the critical value (Sokal and Rohlf 1981). Assumption 3 requires trap efficiency to be constant within each stratum. Many factors can influence trap efficiency including time of release and turbidity (Eskelin 2004), changing stream flow conditions (Volkhardt et al. 2007), fish size and species (Thedinga et al. 1994; Volkhardt et al. 2007), and changes to how the trap is operated (e.g., moved to different positions, addition of screen panels). Marking and releasing fish on a daily basis allowed us to investigate the influence of these variables on capture efficiency. The partial caudal fin-clips used as marks were clearly visible to the crew when recaptured at the screw trap and did not regenerate in the short time period between release and recovery (Assumption 4). Also, the crew was properly trained in fish handling and marking techniques and followed procedures to ensure all captured fish were examined for marks and all marks were reported (Assumption 5). To address Assumption 6, we only marked and released fish classified as smolt or transitional, and we expected most marked smolts to migrate past the trap shortly after their release (Thedinga et al. 1994; Roper and Scarnecchia 1996; Roper and Scarnecchia 1999; Eskelin 2004; Steinhorst et al. 2004; Anderson and Stillwater Sciences 2011).

We used stage height data from the U.S. Geological Survey stream gage site on the South Fork Anchor River, air and water temperature data from the Cook Inletkeeper monitoring program (Sue Mauger, Cook Inletkeeper, personal communication), and trap cone revolutions per minute (RPM) to investigate correlations with trap efficiency using basic data summaries, scatter plots, and statistical analyses. We summarized hourly stage height data and used mean daily stage height in all analyses.

Smolt-to-Spawning Adult Return Rate

We estimated Coho Salmon smolt-to-spawning adult return rate by dividing the count of adult Coho Salmon returning to the Anchor River weir in 2011 (A_{2011}) by the 2010 Coho Salmon smolt abundance estimate ($\hat{U}_{2010}$). This estimate accounts for both fishing and natural mortality, but we are not able to separate the two components. This estimate is possible because of the relatively simple marine life history of Coho Salmon in that nearly all smolts only spend one winter in the ocean before returning as adults (Sandercock 1991). The smolt-to-spawning adult return estimate assumes our count of adult Coho Salmon returning to the Anchor River is a complete census, which we expect to achieve using the weir and underwater video technology (Anderson et al. 2006; Gates and Boersma 2009). Variance was estimated using the Delta method (Seber 1982) as

$$V\left(\frac{A_{2011}}{\hat{U}_{2010}}\right) = \hat{s}^2 = \left(\frac{A_{2011}^2}{\hat{U}_{2010}^4}\right) v(\hat{U})_{2010}.$$

To improve our estimate of smolt-to-spawning adult return rate for Coho Salmon, we estimated numbers of unmarked smolts that migrated past the trap in 2010 when it was not operational during three high water events (Anderson and Stillwater Sciences 2011). Because no relationships between trap efficiency and environmental parameters were identified for the overall period of operations (e.g., stage height, cone RPM, water temperature; Anderson and Stillwater Sciences 2011), we investigated relationships between these parameters and measures of smolt passage during the time periods immediately preceding each high water event. We investigated relationships for Chinook and Coho salmon using simple linear regression, and correlations were considered significant at $P \leq 0.05$. Estimates for missing data were calculated

when possible, and total smolt abundance for 2010 ($\hat{U}_{2010}$) was then recalculated for Chinook and Coho salmon using the equations of Carlson et al. (1998) as described above.

Juvenile Habitat Use

The goal of the habitat use sampling was to describe fish use by habitat type throughout the Anchor River watershed and to describe habitat composition at each of the study reaches as both are important parameters of the RIPPLE model. We accomplished this by estimating abundance of fish in individual habitat units using depletion sampling with three gear types (minnow traps, electrofishing, and seining) and dividing the abundance estimate by the surface area of the unit to calculate densities as number of fish/m^2.

Sample reaches within the Anchor River watershed were chosen using a digital stream network produced by Stillwater Sciences with a high resolution digital elevation model. The stream network was stratified by slope class (%) and drainage area (km^2). Drainage area was determined by calculating watershed area upstream of each channel reach. We also distinguished sites within the Chakok River sub-watershed for separate analysis in RIPPLE based on observed differences in channel morphology (sinuosity, channel form; Stillwater Sciences, unpublished data) from the rest of the Anchor River watershed. Sample reaches were distributed throughout the watershed as much as practical, but accessibility also guided site selection. Within each slope class and sub-watershed, we chose sample reaches that were: 1) accessible within about 1 km from the road system or established trails; 2) on public land or on private land where we could obtain permission to trespass; 3) in areas where we expected to find juvenile salmonids based on Johnson and Klein (2009) and Anderson and Stillwater Sciences (2011); and 4) representative of the different drainage area classes. Sampling at each reach involved collection of fish and aquatic habitat parameters at selected habitat units.

At each sample reach, we attempted to sample fish in different habitat types. A sample size goal of five reaches per slope class was selected based on simulation testing described by Anderson and Stillwater Sciences (2011). Sample reaches were classified following a scheme based on Montgomery and Buffington (1997) that uses channel slope to define process-based channel reach types, which is in accord with the methods used in the RIPPLE model. Individual habitat units within each reach were classified as pool, riffle, run, or plane-bed habitat types based on definitions modified from Bisson et al. (1982), Hankin and Reeves (1988), Montgomery and Buffington (1997), and Overton et al. (1997). Pools were defined as areas with reduced current velocity, often with water deeper than surrounding areas, typically formed by scouring water that has carved out a non-uniform depression in the channel bed or a dam. Runs were defined as deep and fast areas with a defined thalweg and little surface agitation where flow obstructions in the form of boulders may be present. Riffles were defined as shallow areas where water flows swiftly over completely or partially submerged obstructions to produce surface agitation. Plane-bed habitats were defined as long stretches of relatively featureless bed without organized bedforms. Reach lengths were set at 40 wetted channel widths for streams greater than or equal to 3.75 m wide and reach lengths were set at 150 m for streams less than 3.75 m wide (Reynolds et al. 2003). Maximum reach length was limited to 300 m for streams greater than 7.5 m wide to place a maximum effort threshold for each individual sampling reach. Habitat composition within each reach was estimated by beginning at the downstream end of the reach and working upstream for the predetermined reach length. Individual habitat units were classified based on habitat type, and length (m) was measured along the thalweg. A minimum of three widths were measured perpendicular to the thalweg at cross-sections spaced at ¼, ½, and ¾ of the unit's

length, and a mean width (m) was calculated. Surface area of each habitat unit was calculated by multiplying the measured length of the unit by its mean width. Percent composition of each habitat type was summarized by length and surface area for each sample reach.

The spatial coordinates of the downstream end of each sampled reach were recorded in decimal degrees with a handheld global positioning system using the North American Datum of 1983 (NAD83) geographic coordinate system. Water temperature (°C) was measured with a hand-held thermometer and conductivity (µS/cm) for reaches where we sampled with electrofishing was measured using a YSI Model 85 water quality meter.

Fish sampling was conducted using electrofishing, minnow traps, or seines and the gear type was selected based on stream size and stream order (Strahler 1952), which was determined from the digital stream channel network prior to sampling. Electrofishing was only conducted in first or second order streams that flowed into streams no higher than order three to minimize impacts to adult fish.

Regardless of capture method, juvenile salmonids and other non-target fish were identified to species (Pollard et al. 1997), counted, measured for length, and placed in live wells. Scale samples were collected from all juvenile Coho Salmon greater than 60 mm FL. We assumed most Coho Salmon less than 70 mm FL were age 0+ fish based on sampling in other southern Alaska streams (Anderson and Hetrick 2004) but chose to sample fish between 60 and 70 mm to verify this assumption for the Anchor River. Fish were anesthetized and scale samples were collected as previously described. Sampled fish were allowed to recover in a live well prior to release.

Electrofishing —A Smith-Root backpack electrofisher (Model LR-24 or Model 15) was used by a Service-certified operator following the safety guidelines outlined in Reynolds (1996) and USFWS (2004). Output voltage was adjusted to the minimum level necessary to achieve electrotaxis (forced swimming) and pulsed DC was used to minimize fish injury (Dalbey et al. 1996). Electrical output parameters (voltage, current, and power) were recorded along with conductivity (µS/cm) at each location. A visual reconnaissance of each habitat unit was conducted prior to sampling to verify the absence of adult salmonids, and sampling immediately ceased if large salmonids (> 200 mm) were encountered. One person operated the backpack electrofisher and two crew members netted fish.

We used four equal-effort electrofishing removal passes that allowed us to test assumptions of equal capture probability (White et al. 1982). A fifth pass was added if more fish were captured on pass 4 than on pass 3 as recommended by Anderson and Stillwater Sciences (2011) to minimize the number of removal estimate failures. All habitats were thoroughly electrofished on each pass (Riley and Fausch 1992). Block nets were placed at the upstream and downstream ends of the habitat units to prevent immigration and emigration of fish during the removal events. After each electrofishing pass, juvenile fish were processed as described above and placed in live wells. After all passes were completed, block nets were removed and all fish were returned to the habitat unit of capture. We noted any fish mortalities caused by electrofishing.

Minnow Traps. —Minnow traps were used to capture fish from selected habitat units following the procedures of Bryant (2000). Block nets were placed at the upstream and downstream ends of the habitat units to prevent immigration and emigration of fish during the removal events. Four or more capture events were used in each habitat unit so that we could test assumptions of equal capture probability (White et al. 1982). A fifth capture event was added if more fish were

captured on the fourth event than on the third as recommended by Anderson and Stillwater Sciences (2011) to minimize the number of removal estimate failures. Between 8 and 20 minnow traps were set during each event depending on the size of the habitat unit. Distances between traps depended on habitat complexity, but traps were generally separated by about 1.5 m. Traps were set more densely in complex habitats. Traps were set on the stream bottom near large woody debris, root wads, or undercut banks where juvenile salmonids were expected to be present, but were also distributed over the entire habitat unit. Traps were baited with salmon eggs that had been disinfected by soaking for at least 10 minutes in a 1/100 Betadyne solution and placed in a perforated plastic bag. Traps remained undisturbed for 60 ± 5 minutes, and picked up in the order in which they were set. Juvenile fishes were removed from the traps between capture events and processed as described above, and traps were re-set in their original locations. The procedure was repeated for all capture events. After all events were completed, block nets were removed and all fish were returned to the habitat unit of capture. We noted any fish mortalities.

Seines — A two-pole seine, 6.1-m-long by 1.2-m-deep with 3.2-mm (1/8-inch) mesh, was used to capture and juvenile fish from larger habitat units in the North and South forks of the Anchor River, similar to methods described by Curry et al. (2009). Block nets were placed at the upstream and downstream ends of the habitat units to prevent immigration and emigration of fish during the removal events and were held in place by T-bar fence posts driven into the stream bottom and by crew members holding nets. Only three capture events were used in each habitat unit because of the difficulty in holding block nets in place. For each seining pass, a two-person crew would fish the net from the upstream block net to the downstream block net in a series of round hauls, depending on the size of the sampled habitat unit. Following each haul, fish from the seine were placed in buckets for later processing. Following each pass, the lower block net was examined and captured fish were removed and counted during that sampling pass. After each seining pass, juvenile fish were processed as described above and placed in live wells. To assure equal effort, the same number of hauls was conducted on each seining pass. After all passes were completed, block nets were removed and all fish were returned to the habitat unit of capture. We noted any fish mortalities caused by seining.

Data Analysis —Removal estimates and probabilities of capture for electrofishing, seine, and minnow trap experiments were analyzed using Program CAPTURE (White et al. 1982). Program CAPTURE uses catch data from depletion sampling to estimate sampling efficiency and population size and uses two different models to generate population estimates. The first model is equivalent to the trap response model for a closed population (M_b; Pollock et al. 1990) and is based on the assumption of a constant capture probability for all capture events. The second model is equivalent to a heterogeneity and trap response model for a closed population (M_{bh}; Pollock et al. 1990) and is based on the assumption of two different capture probabilities: one for the first capture event and a different probability for the remaining capture events. Program CAPTURE performs a chi-square goodness of fit test for each model to determine whether observed capture probabilities follow those expected for either model. Our four removal events were sufficient to test capture probability assumptions for both models. White et al. (1982) recommend using model results only if probabilities for the model chi-square goodness of fit test were at least 0.20 to avoid bias. The model selected by Program CAPTURE was chosen for analysis purposes, and models were scrutinized if either $P < 0.20$ for any model goodness of fit test, observed capture probabilities were less than 0.20, or population size was less than 200 individuals (White et al. 1982).

Density (number of fish/m^2) for each habitat unit was calculated by dividing the population estimate by the surface area of the unit. Relative density (number of fish/m^2) was also reported for each habitat unit as the total number of fish captured in all sampling events divided by the surface area. Mean densities and mean relative densities by habitat type, slope class, and drainage area were summarized for use as parameters in the RIPPLE model. Basic data summaries, scatter plots, and statistical analyses were used to describe characteristics of sampled fish.

Adult Escapement

We operated a floating resistance board weir installed by the Alaska Department of Fish and Game (ADF&G) to count adult Coho Salmon returning to the Anchor River beginning on August 1, 2011. The weir design and operation is described by Kerkvliet and Booz (2012), and we incorporated an underwater video system similar to that described by Anderson et al. (2006) and Gates and Boersma (2009). Power for the underwater video system was provided by a combination of 12-VDC deep cycle batteries and a gasoline-powered generator. An underwater video camera was placed inside a sealed video box attached to the fish passage chute. The video box was constructed of 3.2-mm aluminum sheeting and filled with filtered water. Safety glass was installed on the front of the video box to allow for a scratch-free, clear surface through which images were captured. The passage chute was constructed from aluminum angle and enclosed in plywood to isolate the video box from exterior light. The backdrop of the passage chute was adjusted laterally to minimize the number of fish passing through the chute at one time. The video box and fish passage chute were artificially lit using a pair of 12-VDC underwater pond lights. Pond lights were equipped with 20-W bulbs which produced a quality image and provided a consistent source of lighting during day and night hours. All video images were recorded on an external 500 gigabyte hard drive at 30 frames-per-second using a computer-based digital video recorder (DVR). The DVR was equipped with motion detection to minimize the amount of blank video footage and review time. Fish passage was recorded 24 hours per day 7 days each week, and stored video files were reviewed several times each day.

Fish were passed continuously through the weir and daily passage counts were tallied by reviewing motion-triggered video files. The DVR has numerous file review features that assist in identification and counting of passing fish. The image can be played forwards or backwards at various speeds, or paused and zoomed to assist in counting or species identification. Once all fish in a file were identified and counted, the next file was reviewed. Video files were reviewed sequentially until all fish passing through the video monitoring chute were identified and counted. Numbers of each species were tallied by sex each hour, when possible, and hourly counts were summed for a daily total. Daily escapement counts were relayed to ADF&G in Homer via cellular telephone.

Results

Smolt Outmigration

We operated a rotary-screw trap in the main-stem Anchor River to capture outmigrating Chinook and Coho salmon smolts continuously from May 18 through July 23, 2011. We were not able to operate the screw trap after July 23 because low water levels and slow velocities prevented the cone from spinning. Nearly all smolt passage occurred at night between 2200 and 0800 hours.

A total of 5,760 Chinook and 6,679 Coho salmon smolts were captured during 2011, of which 1,712 Chinook and 1,863 Coho salmon smolts were marked and 117 and 281 were recaptured,

respectively (Tables 3 and 4). We estimate that 203,775 Chinook (90% C.I.: 137,673 to 269,877) and 56,030 Coho salmon (90% C.I.: 47,302 to 64,758) smolts migrated past the screw trap in 2011 (Tables 3 and 4). These estimates included pooling data for Strata 2 and 3 and Strata 8 and 9 for Chinook Salmon and pooling data for Strata 8 and 9 for Coho Salmon as informed by DARR.

We were able to deploy the rotary-screw trap prior to the smolt outmigration for Chinook and Coho salmon (Figure 2, Appendix A) and were able to operate the trap continuously until removal on July 23. Most Chinook Salmon smolts migrated past the screw trap in late June and early July and peak daily passage (n = 644) occurred on July 3 (Table 3, Figure 2, Appendix A). Chinook Salmon smolt numbers tapered off rapidly in late July with fewer than 10% of smolts captured after July 15. Few Chinook Salmon parr were captured prior to July 1 (Appendix A).

Most Coho Salmon smolts migrated past the screw trap during June with a peak daily passage (n = 1,376) on June 16 (Table 4, Figure 2, Appendix A). Coho Salmon smolt numbers tapered off rapidly in July with less than 6% of smolts captured after July 1. Relatively few Coho Salmon parr (n = 111) were captured in 2011 (Appendix A).

In addition to Chinook and Coho salmon, other species captured in the screw trap included adult Chinook Salmon; juvenile and adult Pink Salmon; Dolly Varden smolts, parr, and adults; steelhead smolts; juvenile *O. mykiss;* Threespine Stickleback, Lamprey *Lampetra* spp., Eulachon, and Sculpin *Cottus* spp. Dolly Varden smolts passed the rotary-screw trap in large numbers in late May and most steelhead smolt passage occurred in July (Appendix A).

Mark-recapture assumptions for the screw trap capture efficiency estimates were valid most of the time, and the methods we adopted to address assumptions were described above. Mortality of tagged fish (Assumption 1) was low overall, and totals of n = 4 marked Chinook Salmon and n = 3 marked Coho Salmon were mortalities observed in the release site live well. These mortalities were subtracted from the marked total in their respective strata.

Although size of Coho Salmon smolts varied over the sampling period (Figure 3; Table 5), we observed no difference in size distributions for Coho Salmon (Assumption 2) and the Kolmogorov-Smirnov two-sample test comparing length-frequency distributions of marked and recaptured fish was not different at $\alpha = 0.05$ (D = 0.073, critical value = 0.087; Figure 4). The size of Chinook Salmon smolts also varied over the sampling period (Figure 3; Table 6) and the Kolmogorov-Smirnov two-sample test for length distributions was greater than the critical value at $\alpha = 0.05$ (D = 0.17; critical value = 0.13; Figure 5) indicating the length distributions for marked and recaptured fish were different. Sample size goals to meet the desired precision specified in Objective 2 were achieved during most strata for Coho Salmon (Table 5) but were only achieved during three strata for Chinook Salmon (Table 6).

Once the screw trap was positioned on May 18, it fished in the same position for the rest of the sampling period and trap operations were consistent each day, including time of release each evening (Assumption 3). However, capture efficiencies for Chinook and Coho salmon varied over the sampling season (Assumption 3; Tables 5 and 6) and G-tests of independence

Table 3. Mark-recapture abundance estimates and 90% confidence intervals (C.I.) of Chinook Salmon smolts migrating in the Anchor River, 2011. M_h is the number of marked smolts released in stratum *h*, m_h is the number of marked smolts recaptured in *h*, u_h is the number of unmarked smolts captured in *h*, and $\hat{U}_h$ is the smolt population size excluding marked releases and observed in *h*.

Stratum	M_h	m_h	u_h	$\hat{U}_h$	Lower C.I.	Upper C.I.
1	32	7	69	285	141	428
2-3	47	5	57	456	177	735
4	196	37	385	1,996	1,501	2,491
5	299	42	536	3,740	2,847	4,632
6	315	12	1,402	34,079	19,340	48,819
7	315	8	2,062	72,399	35,197	109,601
8-9	508	6	1,249	90,820	38,217	143,423
Total	1,712	117	5,760	203,775	137,673	269,877

Table 4. Mark-recapture abundance estimates and 90% confidence intervals (C.I.) of Coho Salmon smolts migrating in the Anchor River, 2011. M_h is the number of marked smolts released in stratum *h*, m_h is the number of marked smolts recaptured in *h*, u_h is the number of unmarked smolts captured in *h*, and $\hat{U}_h$ is the smolt population size excluding marked releases and observed in *h*.

Stratum	M_h	m_h	u_h	$\hat{U}_h$	Lower C.I.	Upper C.I.
1	82	29	87	241	175	307
2	302	82	621	2,267	1,898	2,636
3	315	50	1,346	8,340	6,565	10,115
4	315	45	2,641	18,143	14,084	22,201
5	313	42	860	6,280	4,797	7,763
6	286	13	847	17,364	10,112	24,615
7	163	16	186	1,794	1,106	2,482
8-9	87	4	91	1,602	529	2,674
Total	1,863	281	6,679	56,030	47,302	64,758

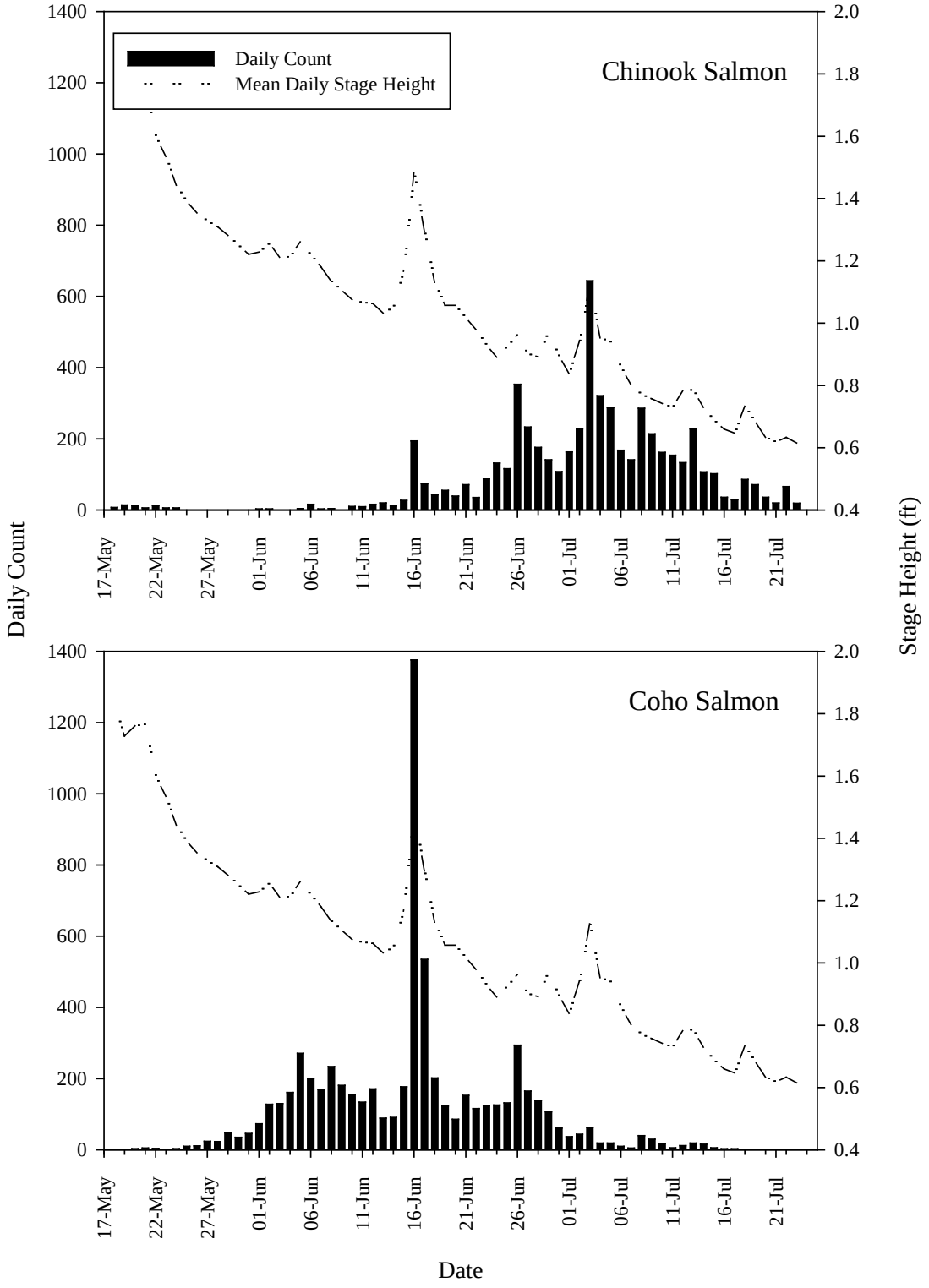

Figure 2. Daily counts in relation to stage height for Chinook (top) and Coho (bottom) salmon at the Anchor River rotary-screw trap, 2011.

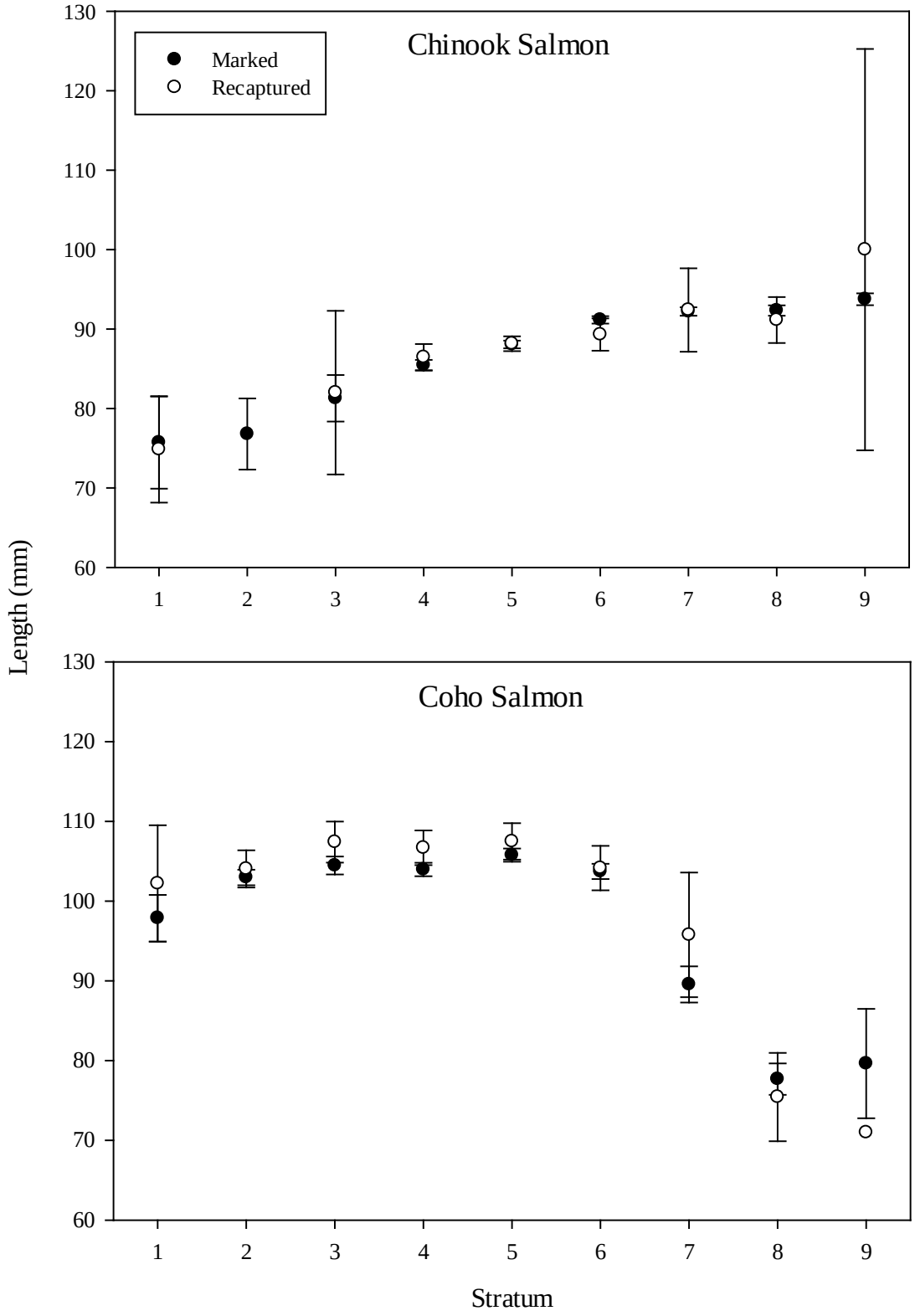

Figure 3. Mean fork lengths and 95% confidence intervals by tagging strata for Chinook (top) and Coho (bottom) salmon marked and recaptured at the Anchor River rotary-screw trap in 2011.

Table 5. Contingency table used to test for equal capture probability of Coho Salmon smolts migrating in the Anchor River, 2011. M_h is the number of marked smolts released in stratum *h*, m_h is the number of marked smolts recaptured in *h*, and M_h - m_h is the number not recaptured. Also reported are estimated capture efficiencies (%) and mean fork lengths (SE in parentheses) of smolts marked and recaptured.

					Mean Smolt FL (mm)	
Stratum	m_h	M_h - m_h	M_h	Capture Efficiency	Marked	Recaptured
1	29	53	82	35.4	97.9 (1.8)	102.2 (4.3)
2	82	220	302	27.2	103.0 (0.6)	104.0 (1.4)
3	50	265	315	15.9	104.5 (0.7)	107.4 (1.5)
4	45	270	315	14.3	104.0 (0.5)	106.7 (1.3)
5	42	271	313	13.4	105.8 (0.5)	107.5 (1.4)
6	13	273	286	4.5	103.7 (0.6)	104.1 (1.6)
7	16	147	163	9.8	89.6 (1.4)	95.8 (4.4)
8	4	74	78	5.1	77.7 (1.2)	75.4 (2.9)
9	0	9	9	0.0	79.6 (3.8)	71.0 (--)
Total	281	1,582	1,863	15.1	101.4 (0.3)	104.2 (0.8)

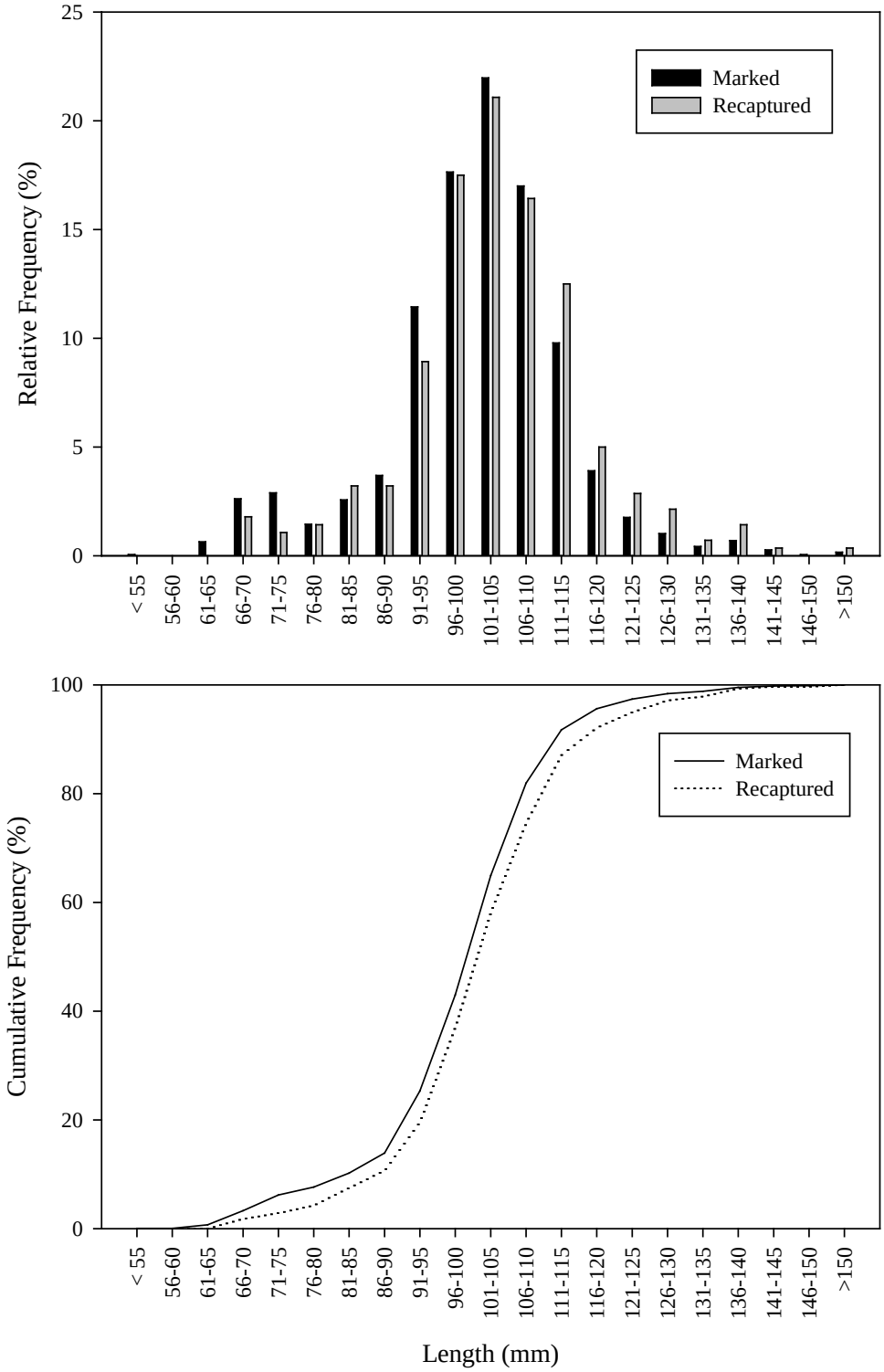

Figure 4. Length-frequency distribution (top) and cumulative frequency distribution (bottom) of Coho Salmon marked and recaptured at the Anchor River rotary-screw trap, 2011.

Table 6. Contingency table used to test for equal capture probability of Chinook Salmon smolts migrating in the Anchor River, 2011. M_h is the number of marked smolts released in stratum *h*, m_h is the number of marked smolts recaptured in *h*, and M_h - m_h is the number not recaptured. Also reported are estimated capture efficiencies (%) and mean fork lengths (SE in parentheses) of smolts marked and recaptured.

					Mean Smolt FL (mm)	
Stratum	m_h	M_h - m_h	M_h	Capture Efficiency	Marked	Recaptured
1	7	25	32	21.9	75.7 (3.4)	74.9 (3.4)
2	0	10	10	0.0	76.8 (2.4)	--
3	5	32	37	13.5	81.3 (1.7)	82.0 (4.8)
4	37	159	196	18.9	85.5 (0.4)	86.5 (1.0)
5	42	257	299	14.0	88.1 (0.3)	88.1 (0.6)
6	12	303	315	3.8	91.2 (0.3)	89.3 (1.2)
7	8	307	315	2.5	92.2 (0.3)	92.4 (2.5)
8	4	300	304	1.3	92.3 (0.4)	91.1 (1.5)
9	2	202	204	1.0	93.8 (0.5)	100.0 (4.0)
Total	117	1,595	1,712	6.8	90.1 (0.2)	87.4 (0.6)

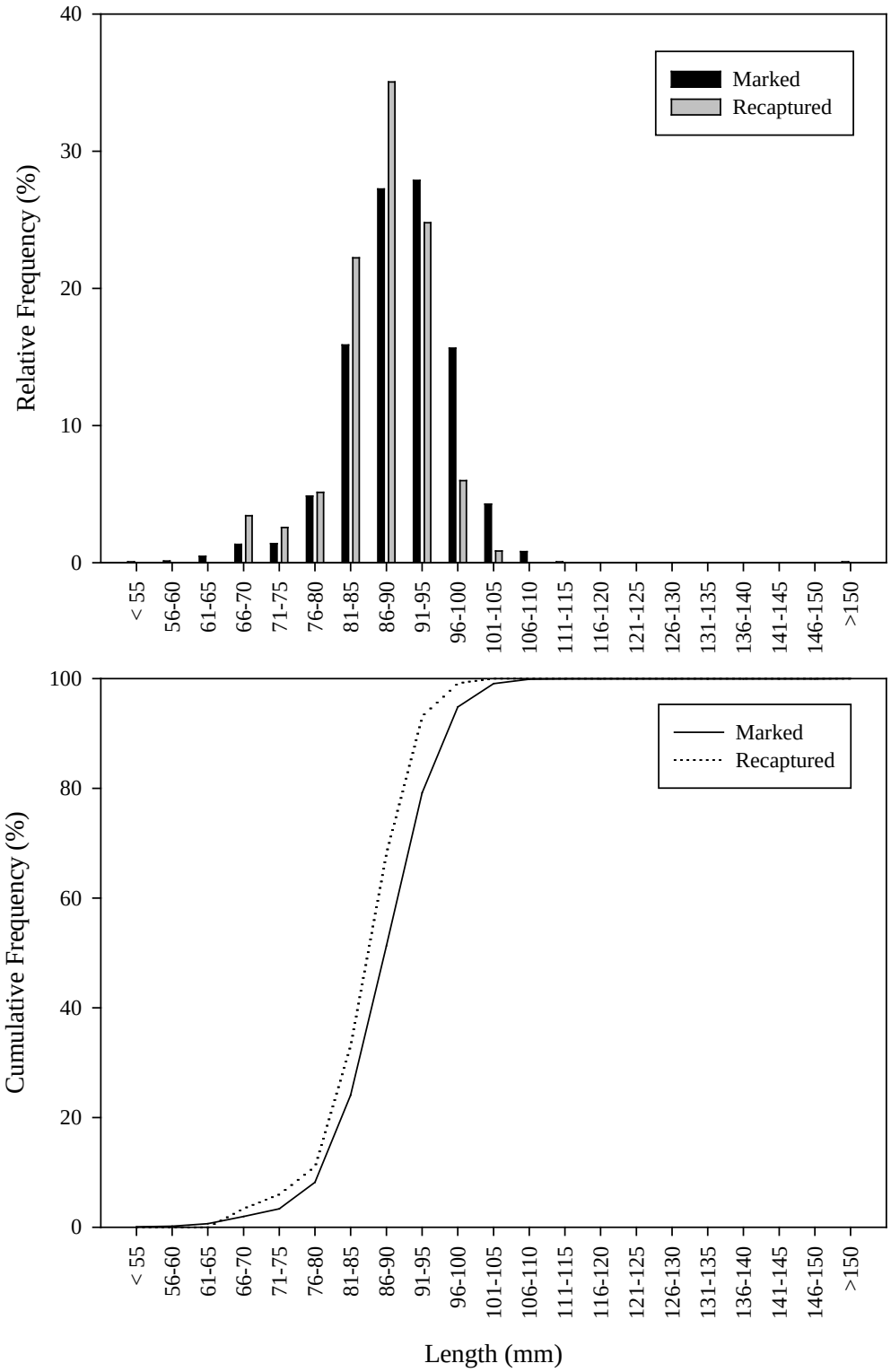

Figure 5. Length-frequency distribution (top) and cumulative frequency distribution (bottom) of Chinook Salmon marked and recaptured at the Anchor River rotary-screw trap, 2011.

indicate capture efficiency data for Chinook (G_{adj} = 107.9; $P < 0.0001$) and Coho salmon (G_{adj} = 95.7; $P < 0.0001$) are not independent of tagging strata and should not be pooled. Mean daily stage height (Figure 2) also varied over the course of the season, and significant relationships were found between stage height and daily capture efficiencies for Chinook ($r^2 = 0.19$, $P < 0.001$) and Coho salmon ($r^2 = 0.46$, $P < 0.001$; Assumption 3). Significant relationships were also found between cone RPM and capture efficiencies for Chinook ($r^2 = 0.15$; $P < 0.002$) and Coho salmon ($r^2 = 0.52$; $P < 0.001$). In general, capture efficiencies for both species were higher during higher stream flows.

Most marked Chinook and Coho salmon were recaptured within a few days of release and most were usually recaptured the following morning after release (Assumption 6), although $n = 2$ Chinook and $n = 1$ Coho salmon were recaptured in a different stratum than released. Since we did not apply differential daily marks, we are unable to estimate daily capture efficiencies because the number of fish available for capture upstream of the trap on any given day may have been greater than the number recently released.

Three ages were identified for $n = 332$ Chinook Salmon smolts sampled at the rotary-screw trap between May 19 and July 19 and all but 8 were age 1 (Figure 6). Three ages were also identified for $n = 342$ Coho Salmon smolts sampled at the rotary-screw trap between May 20 and July 3, and most fish (75%) were age 2 (Table 7, Figure 6). Most Coho Salmon longer than 95 mm FL were age 2 smolts and most less than 95 mm were age 1, although there was overlap from 90 to 110 mm (Figure 6).

We were able to estimate numbers of unmarked Chinook and Coho salmon smolts passing the rotary-screw trap when it was inoperable on July 14 and 27, 2010, because of high water events. Significant linear regression relationships were found using data immediately preceding the high water event and good predictive relationships were found (Figures 7 and 8). However, these inferences are outside of the range of observed data and should be viewed with caution. Using these relationships, we estimate 905 unmarked Chinook and 1,436 unmarked Coho salmon smolt passed the smolt trap on July 14, and 711 unmarked Chinook and 253 unmarked Coho salmon smolt passed the trap on July 27 (Figure 9). Using these values for unmarked smolt (u_h) results in estimates of 81,700 (90% C.I. 72,268-91,132) Chinook Salmon and 65,156 (90% C.I.: 57,508-72,805) Coho Salmon smolt passing the rotary-screw trap in 2010 ($\hat{U}_{2010}$) (Table 8). We were unable to estimate numbers of unmarked Chinook and Coho salmon smolts when the rotary-screw trap was inoperable August 4–5, 2010, because no predictive relationship was found between changing flow conditions (stage height or cone RPM) and measures of smolt capture (capture efficiency, smolt numbers, CPUE).

Smolt-to-Spawning Adult Return Rate

Using a revised estimate of Coho Salmon smolt abundance in 2010 ($\hat{U}_{2010}$) of 65,156 and the estimated adult escapement of Coho Salmon in 2011 (A_{2011}; see below) of 1,866, we estimated a smolt-to-spawning adult return rate of 0.029 (SD = 0.002). Estimated smolt-to-spawning adult return rate using the uncorrected 2010 Coho Salmon smolt abundance estimate ($\hat{U}_{2010}$ = 50,688) is 0.037 (SD = 0.003).

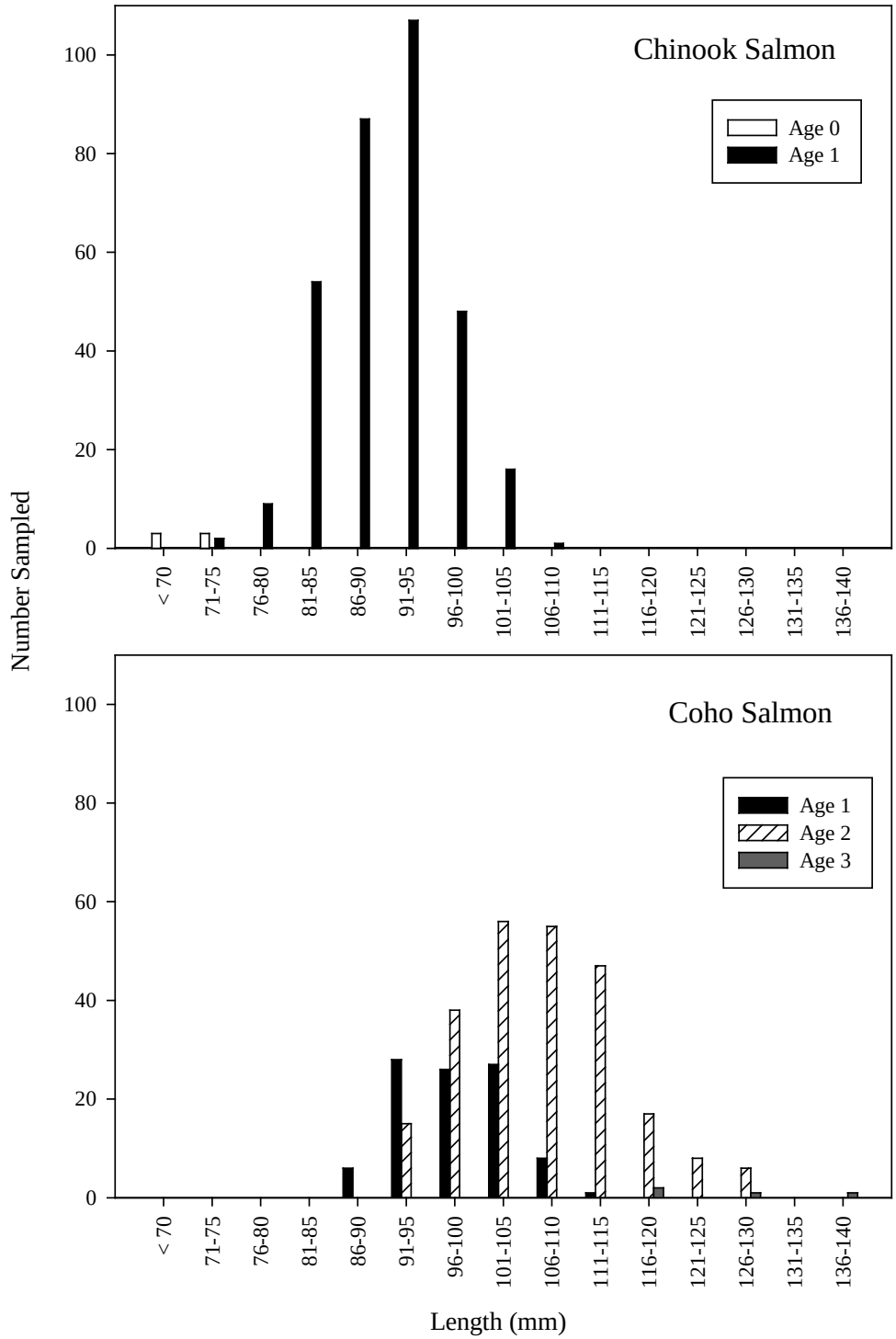

Figure 6. Length composition by age for Chinook and Coho salmon smolts sampled at the Anchor River rotary-screw trap between May 18 and July 3, 2011. Chinook Salmon panel does not include *n* = 2 smolts that were age 3 (FL = 180 and 200 mm).

Table 7. Age composition and mean fork length of Coho Salmon smolts sampled at the Anchor River rotary-screw trap between May 18 and July 3, 2011.

	Age		
	1	2	3
		Stratum 1	
Proportion	0.27	0.71	0.02
SE (proportion)	0.06	0.07	0.02
Mean Length (mm)	98.0	107.0	- -
SE (length)	1.9	1.5	- -
n	12	32	1
		Stratum 2	
Proportion	0.26	0.74	0.00
SE (proportion)	0.05	0.05	- -
Mean Length (mm)	96.9	106.7	- -
SE (length)	1.1	1.0	- -
n	20	57	0
		Stratum 3	
Proportion	0.17	0.82	0.01
SE (proportion)	0.04	0.04	0.01
Mean Length (mm)	97.6	107.3	- -
SE (length)	1.6	1.0	- -
n	13	63	1
		Stratum 4	
Proportion	0.34	0.65	0.01
SE (proportion)	0.05	0.05	0.01
Mean Length (mm)	99.7	107.7	- -
SE (length)	1.0	1.1	- -
n	26	50	1

Table 7. continued.

	Age		
	1	2	3
		Stratum 5	
Proportion	0.38	0.61	0.02
SE (proportion)	0.06	0.06	0.01
Mean Length (mm)	98.9	106.6	- -
SE (length)	1.0	1.2	- -
n	25	40	1
		Total	
Proportion	0.25	0.74	0.01
SE (proportion)	0.02	0.02	0.01
Mean Length (mm)	98.1	107.1	123.1
SE (length)	2.4	4.2	4.2
n	96	242	4

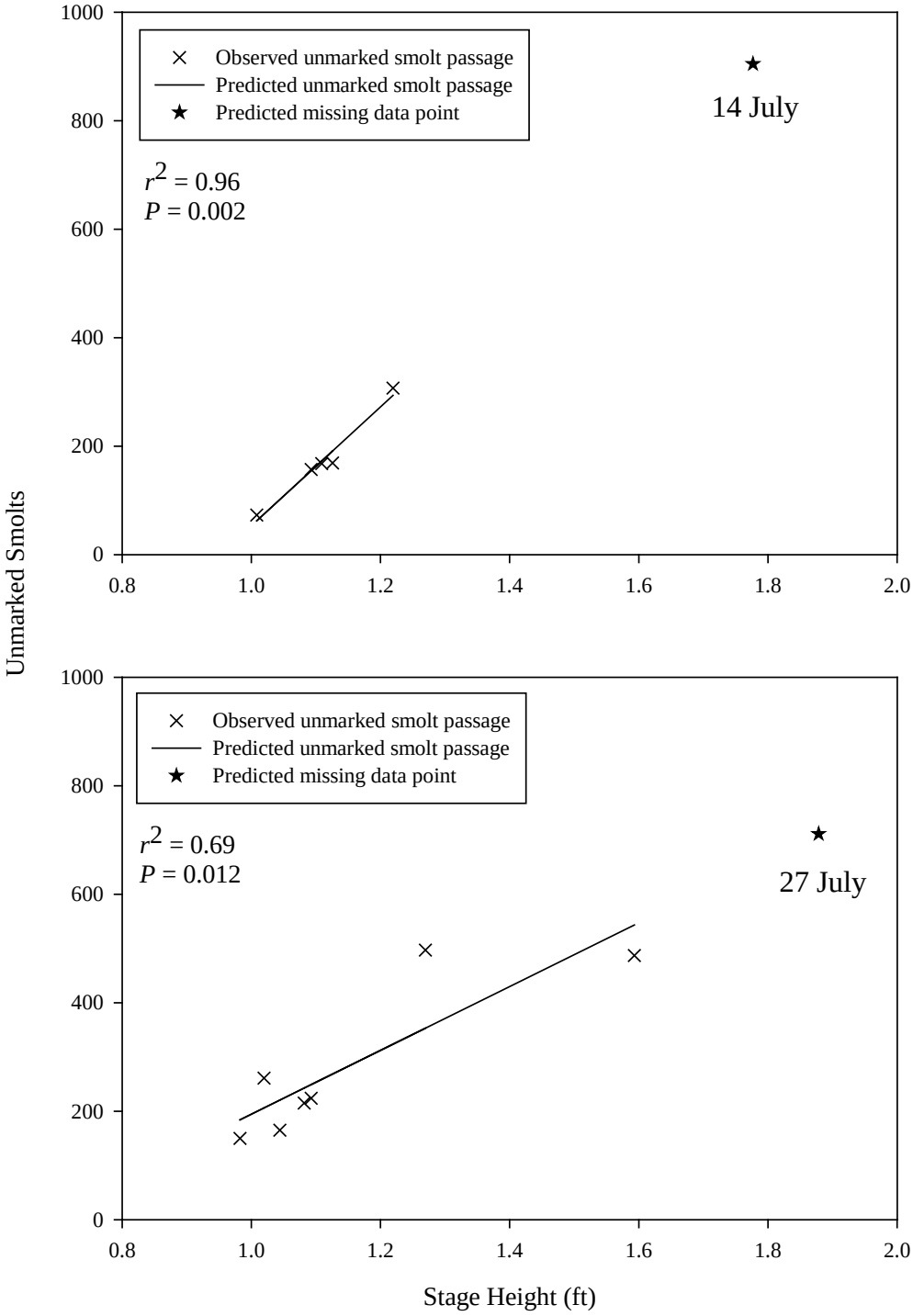

Figure 7. Fitted regression lines used to predict numbers of unmarked Chinook Salmon smolts during periods that the rotary-screw trap was inoperable on July 14 (top) and July 27 (bottom), 2010.

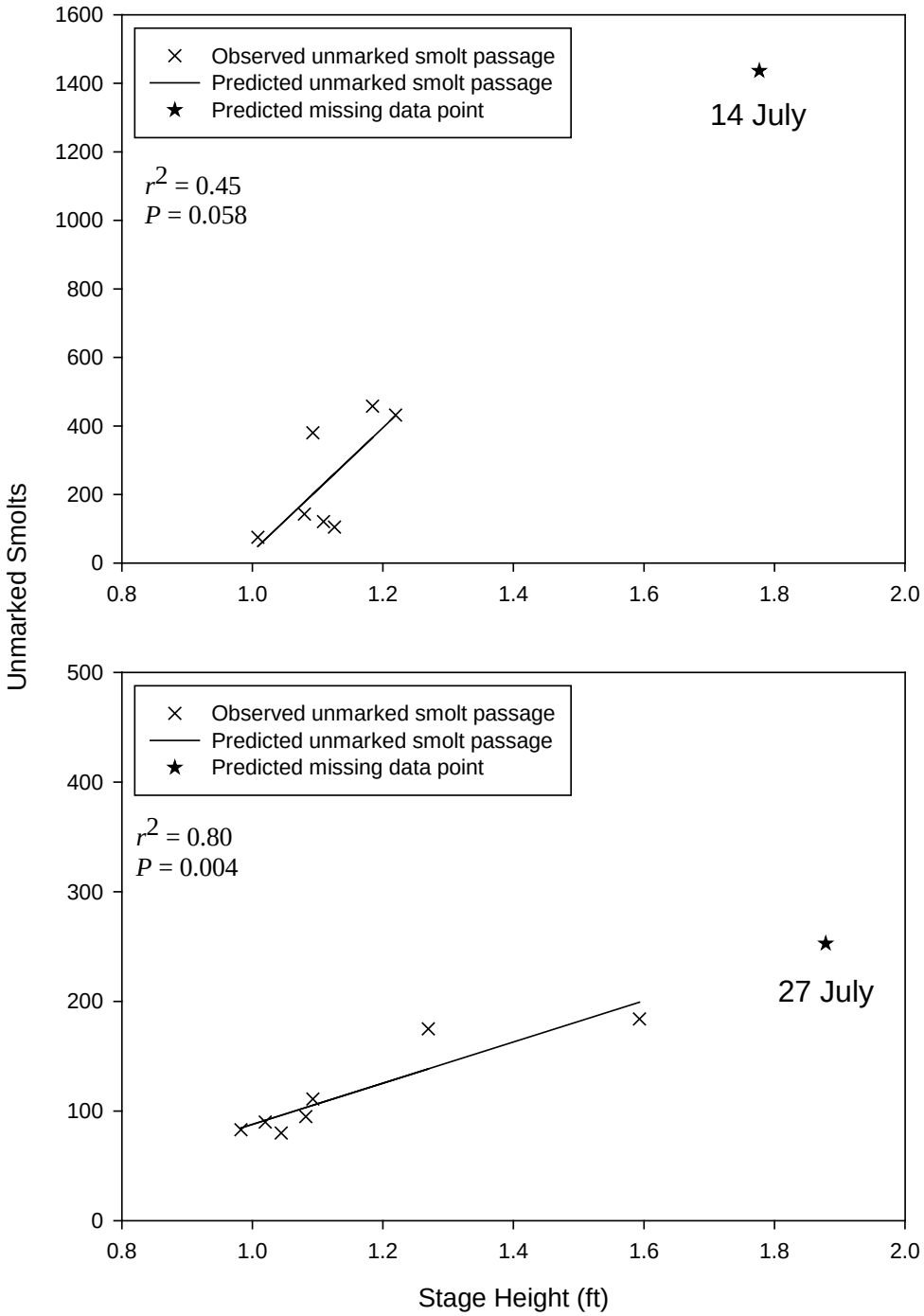

Figure 8. Fitted regression lines used to predict numbers of unmarked Coho Salmon smolts during periods that the rotary-screw trap was inoperable on July 14 (top) and July 27 (bottom), 2010.

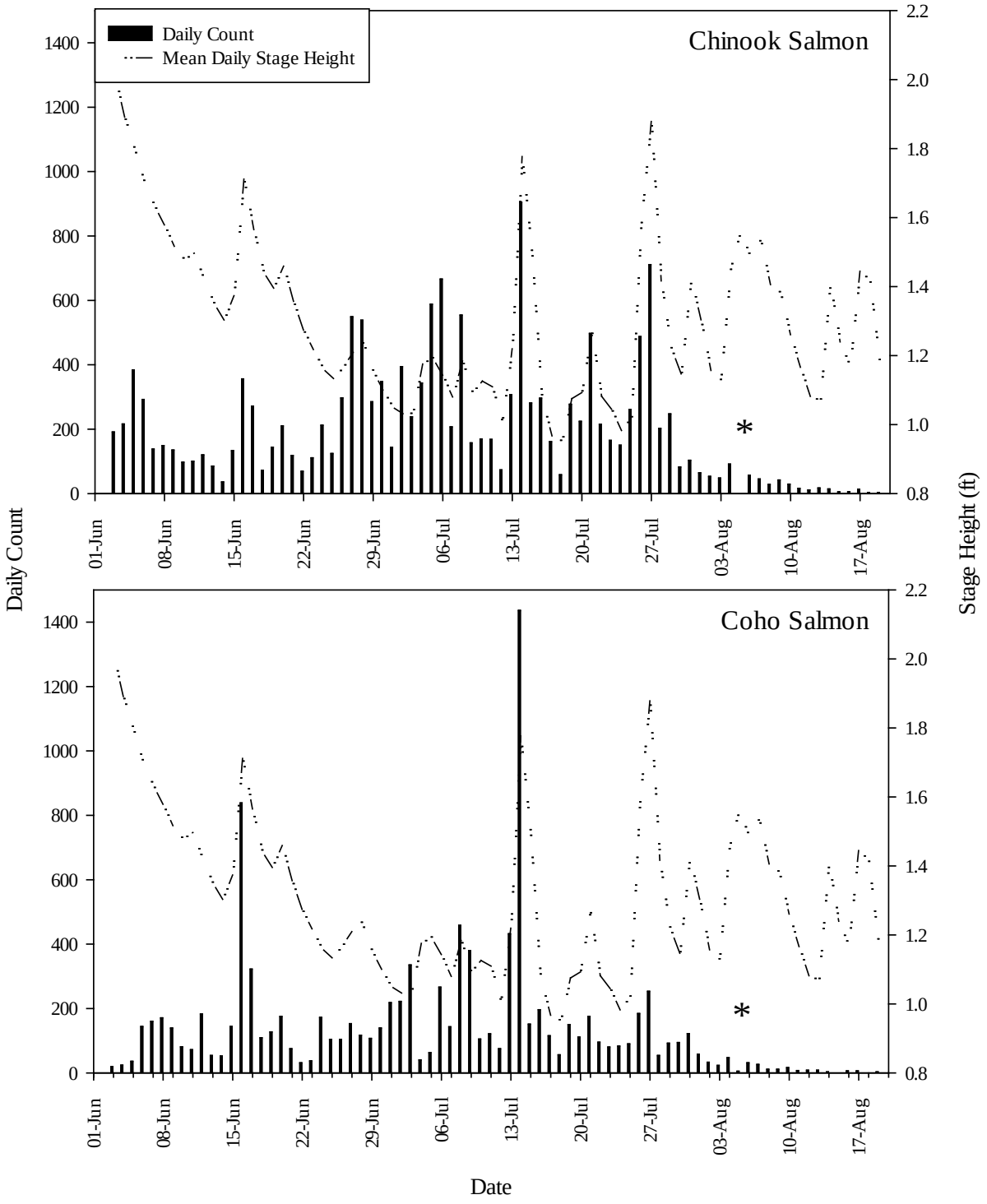

Figure 9. Daily counts including estimates for missing data on July 14 and 27 in relation to stage height for Chinook (top) and Coho (bottom) salmon at the Anchor River rotary-screw trap, 2010. An asterisk (*) indicates incomplete count for August 5.

Table 8. Comparison of Chinook and Coho salmon smolt abundance estimates and confidence intervals (C.I.) as reported for 2010 (Anderson and Stillwater Sciences 2011) and revised using estimates for missing data on July 14 and 27, 2010.

	Estimate	Lower 90% C.I.	Upper 90% C.I.
		Chinook Salmon	
2010 Estimate	75,052	65,847	84,257
Revised Estimate	81,700	72,268	91,132
Percent Difference	8.9%	9.8%	8.2%
		Coho Salmon	
2010 Estimate	50,688	46,141	55,234
Revised Estimate	65,156	57,508	72,805
Percent Difference	28.5%	24.6%	31.8%

Juvenile Habitat Use

Juvenile fish and habitat surveys were conducted in 92 distinct habitat units in 25 reaches from July 6 to September 16, 2011; 44 habitat units were sampled using backpack electrofishing gear, 38 units were sampled with minnow traps, and 10 habitat units were sampled with seines. (Figure 10). Dolly Varden were the most widely distributed species and were observed in 75 of 92 habitat units; juvenile Coho Salmon were observed in 74 habitat units, and juvenile Chinook Salmon and juvenile *O. mykiss* were observed in 44 habitat units (Tables 9 and 10). Dolly Varden was the only species present in nine habitat units, and we did not capture any fish in three habitat units. Habitat composition data for our sampled reaches are summarized in Table 11.

Program CAPTURE produced valid abundance estimates for 77% of habitat units for Chinook and Coho salmon, 73% of habitat units for Dolly Varden, and 50% of habitat units for juvenile *O. mykiss* (Table 12). Removal estimate models failed when depletion did not occur on subsequent capture occasions.

In general, juvenile Coho Salmon were observed at higher densities in smaller streams (0-10 km^2 drainage area) and juvenile Chinook Salmon were observed at higher densities in larger (> 10 km^2 drainage area) streams (Tables 9 and 10). Juvenile Chinook Salmon were more abundant in streams with gradients < 1% and none were observed in any habitat unit above 3% gradient. Coho Salmon were more broadly distributed among all slope classes but fewer were observed in gradients > 3% (Tables 9 and 10). Both species were found in pool and run habitats at higher densities than in riffles, although fewer riffles were sampled than other habitat types.

Lengths of juvenile Chinook Salmon sampled in 2011 using minnow traps, electrofishing, and seines ranged from 27 to 105 mm FL although most were less than 75 mm; Coho Salmon lengths ranged from 26 to 115 mm and most were less than 70 mm (Figure 11). Dolly Varden sampled in 2011 ranged in length from 17 to 194 mm, and juvenile *O. mykiss* lengths ranged from 32 to

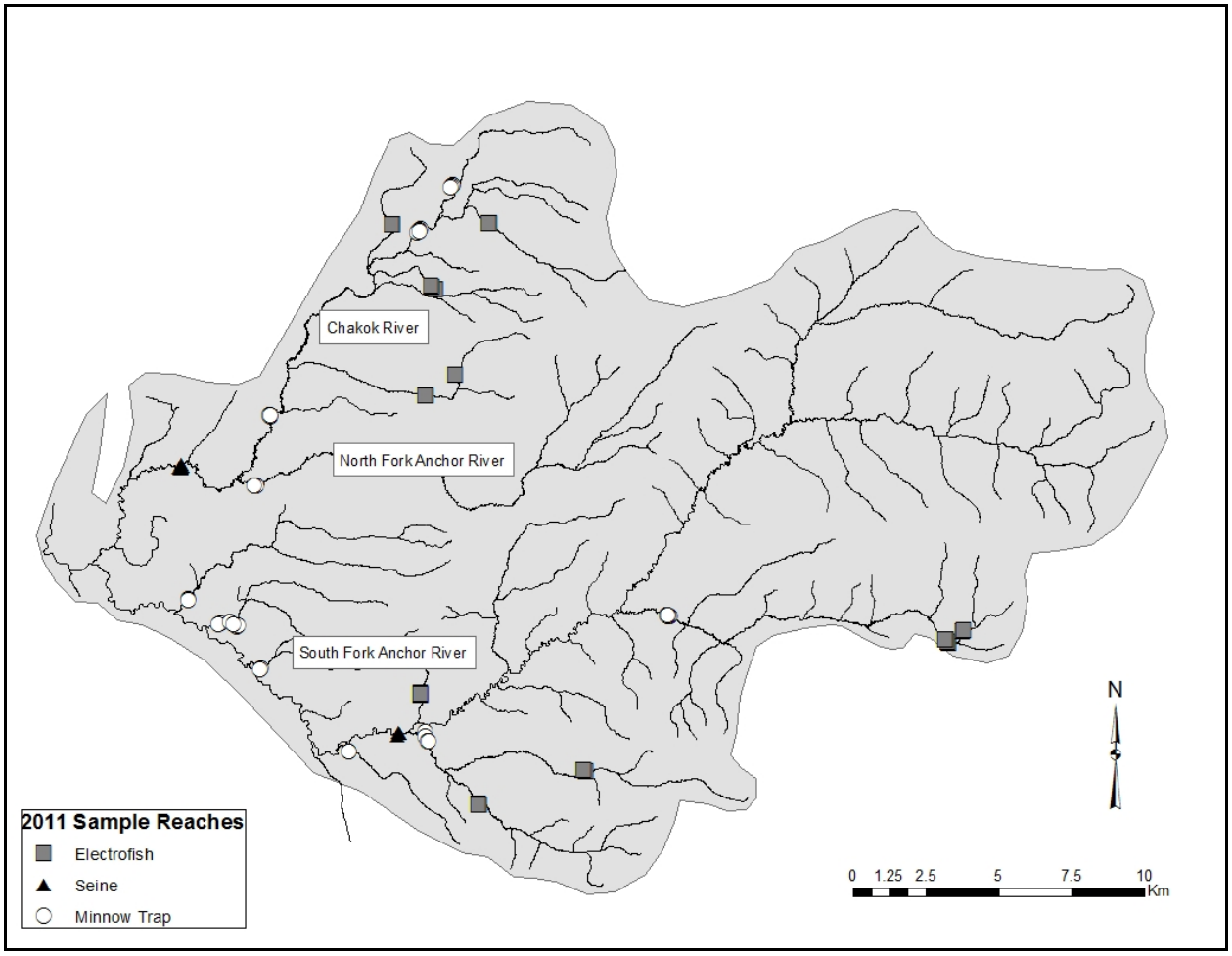

Figure 10. Distribution of reaches in the Anchor River watershed sampled with electrofishing, seines, and minnow traps, 2011.

Table 9. Summary of minnow trapping, seining, and electrofishing mean density removal estimates (fish/m^2; SD of the mean in parenthesis) in the Anchor River watershed by system, slope class, drainage area, and habitat type, 2011. Numbers of habitat units sampled are reported as *n*. CO = Coho Salmon; CK = Chinook Salmon; DV = Dolly Varden.

System	Slope Class	Drainage Area	Habitat Type	*n*	CO	CK	DV	*O. mykiss*
Anchor	0 to 1%	0-10 km^2	Pool	3	4.45 (0.44)	0.00 (0.00)	0.26 (0.40)	0.00 (0.00)
			Riffle	2	0.66 (0.09)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
			Run	3	0.97 (0.75)	0.00 (0.00)	0.07 (0.13)	0.00 (0.00)
		10-50 km^2	Pool	6	0.52 (0.46)	1.06 (0.86)	0.89 (0.91)	0.12 (0.03)
			Riffle	0	--	--	--	--
			Run	6	0.20 (0.18)	0.76 (0.80)	0.78 (0.77)	0.24 (0.10)
		50-100 km^2	Pool	2	0.63 (0.09)	3.61 (0.11)	0.18 (0.23)	0.56 (0.03)
			Riffle	0	--	--	--	--
			Run	2	0.14 (0.13)	0.62 (0.01)	0.04 (--)	0.34 (--)
		100-250 km^2	Pool	3	0.16 (0.12)	0.40 (0.15)	0.01 (0.01)	*
			Riffle	1	0.00 (--)	*	0.00 (--)	0.00 (--)
			Run	3	0.00 (0.00)	0.13 (0.13)	0.00 (0.00)	0.08 (0.02)
		> 250 km^2	Pool	1	0.00 (--)	0.57 (--)	*	*
			Riffle	0	--	--	--	--
			Run	2	0.02 (0.03)	0.13 (0.17)	*	0.00 (--)
	1 to 3%	0-10 km^2	Pool	5	1.94 (2.07)	0.19 (0.26)	1.89 (1.44)	0.00 (0.00)
			Riffle	1	0.95 (--)	0.00 (--)	2.61 (--)	0.00 (--)
			Run	5	1.19 (1.31)	0.06 (0.08)	1.89 (1.68)	0.00 (0.00)
		10-50 km^2	Pool	4	0.56 (0.11)	0.62 (0.89)	0.61 (0.23)	0.03 (0.04)
			Riffle	2	0.36 (0.01)	0.00 (--)	1.12 (0.71)	0.07 (0.10)
			Run	4	0.56 (0.01)	0.34 (0.41)	0.89 (0.36)	0.08 (0.08)
	3 to 5%	0-10 km^2	Pool	2	0.00 (0.00)	0.00 (0.00)	0.00 (--)	0.00 (0.00)
			Riffle	2	0.00 (0.00)	0.00 (0.00)	0.00 (--)	0.00 (0.00)
			Run	2	0.15 (0.22)	0.00 (0.00)	1.85 (--)	0.00 (0.00)
		10-50 km^2	Pool	1	0.00 (--)	0.00 (--)	*	0.00 (--)
			Riffle	0	--	--	--	--
			Run	1	0.00 (0.00)	0.00 (--)	*	*
Chakok	0 to 1%	0-10 km^2	Pool	5	0.19 (0.33)	0.00 (0.00)	0.42 (0.72)	0.00 (0.00)
			Riffle	0	--	--	--	--
			Run	4	0.58 (0.82)	0.00 (0.00)	0.79 (0.60)	0.05 (0.08)
		50-100 km^2	Pool	2	0.10 (0.01)	0.01 (--)	0.00 (--)	0.11 (--)
			Riffle	0	--	--	--	--
			Run	2	0.13 (0.00)	*	0.00 (0.00)	0.13 (0.01)

- continued -

Table 9. continued.

System	Slope Class	Drainage Area	Habitat Type	*n*	CO	CK	DV	*O. mykiss*
Chakok	1 to 3%	0-10 km^2	Pool	3	0.76 (0.35)	0.18 (0.31)	2.06 (2.13)	0.00 (0.00)
			Riffle	3	0.14 (0.19)	0.00 (0.00)	1.67 (0.93)	0.00 (0.00)
			Run	3	1.13 (0.33)	0.00 (0.00)	1.76 (0.25)	0.00 (0.00)
		10-50 km^2	Pool	3	0.75 (0.59)	1.37 (2.05)	2.75 (2.43)	0.00 (--)
			Riffle	1	0.00 (--)	0.00 (--)	*	0.00 (--)
			Run	3	0.16 (0.03)	0.64 (0.90)	2.98 (1.55)	0.05 (0.08)

* = Population estimate could not be calculated, but species was captured

Table 10. Summary of minnow trapping, seining, and electrofishing mean relative density estimates (fish/m^2; SD of the mean in parenthesis) in the Anchor River watershed by system, slope class, drainage area, and habitat type, 2011. Numbers of habitat units sampled are reported as *n*. CO = Coho Salmon; CK = Chinook Salmon; DV = Dolly Varden.

System	Slope Class	Drainage Area	Habitat Type	*n*	CO	CK	DV	*O. mykiss*
Anchor	0 to 1%	0-10 km^2	Pool	3	1.82 (1.24)	0.00 (0.00)	0.26 (0.40)	0.00 (0.00)
			Riffle	2	0.54 (0.26)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
			Run	3	0.90 (0.66)	0.00 (0.00)	0.07 (0.13)	0.00 (0.00)
		10-50 km^2	Pool	6	0.46 (0.40)	0.89 (0.72)	0.79 (0.82)	0.11 (0.04)
			Riffle	0	--	--	--	--
			Run	6	0.17 (0.13)	0.69 (0.60)	0.43 (0.37)	0.11 (0.09)
		50-100 km^2	Pool	2	0.60 (0.04)	3.18 (0.10)	0.18 (0.22)	0.38 (0.04)
			Riffle	0	--	--	--	--
			Run	2	0.10 (0.07)	0.60 (0.03)	0.03 (0.01)	0.21 (0.07)
		100-250 km^2	Pool	3	0.11 (0.09)	0.29 (0.14)	0.01 (0.00)	0.15 (0.16)
			Riffle	1	0.00 (--)	0.01 (--)	0.00 (--)	0.00 (--)
			Run	3	0.02 (0.03)	0.13 (0.13)	0.00 (0.00)	0.06 (0.02)
		> 250 km^2	Pool	1	0.00 (--)	0.56 (--)	0.03 (--)	0.02 (--)
			Riffle	0	--	--	--	--
			Run	2	0.02 (0.03)	0.12 (0.16)	0.01 (0.01)	0.00 (0.00)
	1 to 3%	0-10 km^2	Pool	5	1.61 (1.73)	0.19 (0.26)	1.61 (1.21)	0.01 (0.03)
			Riffle	1	0.76 (--)	0.00 (--)	2.35 (--)	0.00 (--)
			Run	5	0.72 (0.87)	0.06 (0.08)	1.37 (1.28)	0.00 (0.00)
		10-50 km^2	Pool	4	0.50 (0.07)	0.47 (0.77)	0.52 (0.15)	0.06 (0.05)
			Riffle	2	0.36 (0.01)	0.04 (0.05)	0.93 (0.45)	0.07 (0.10)
			Run	4	0.28 (0.24)	0.26 (0.35)	0.60 (0.31)	0.07 (0.07)
	3 to 5%	0-10 km^2	Pool	2	0.00 (0.00)	0.00 (0.00)	1.20 (1.69)	0.00 (0.00)
			Riffle	2	0.00 (0.00)	0.00 (0.00)	0.45 (0.64)	0.00 (0.00)
			Run	2	0.15 (0.22)	0.00 (0.00)	1.33 (0.59)	0.00 (0.00)
		10-50 km^2	Pool	1	0.00 (--)	0.00 (--)	0.20 (--)	0.00 (--)
			Riffle	0	--	--	--	--
			Run	1	0.00 (--)	0.00 (--)	0.65 (--)	0.04 (--)
Chakok	0 to 1%	0-10 km^2	Pool	5	0.44 (0.70)	0.00 (0.00)	0.64 (0.70)	0.04 (0.06)
			Riffle	0	--	--	--	--
			Run	4	0.40 (0.52)	0.01 (0.02)	0.64 (0.52)	0.04 (0.06)
		50-100 km^2	Pool	2	0.10 (0.02)	0.02 (0.01)	0.01 (0.01)	0.07 (0.01)
			Riffle	0	--	--	--	--
			Run	2	0.13 (0.00)	0.02 (0.01)	0.00 (0.00)	0.12 (0.01)

- continued-

Table 10. continued.

System	Slope Class	Drainage Area	Habitat Type	*n*	CO	CK	DV	*O. mykiss*
Chakok	1 to 3%	0-10 km^2	Pool	3	0.86 (0.33)	0.18 (0.31)	1.62 (1.49)	0.00 (0.00)
			Riffle	3	0.12 (0.14)	0.00 (0.00)	1.11 (0.75)	0.00 (0.00)
			Run	3	0.75 (0.32)	0.00 (0.00)	1.48 (0.08)	0.00 (0.00)
		10-50 km^2	Pool	3	0.56 (0.42)	0.90 (1.28)	2.03 (1.41)	0.03 (0.03)
			Riffle	1	0.00 (--)	0.00 (--)	0.58 (--)	0.00 (--)
			Run	3	0.12 (0.07)	0.55 (0.56)	2.16 (0.80)	0.05 (0.08)

Table 11. Summary of habitat composition in the Anchor River watershed, 2011. Numbers of habitat units sampled are reported as *n*.

System	Slope Class	Drainage Area	Habitat Type	*n*	Length (m) Total	Length (m) Composition (%)	Surface Area (m^2) Total	Surface Area (m^2) Composition (%)
Anchor	0 to 1%	10-50 km^2	Pool	4	41	29	87	28
			Riffle	4	23	16	48	15
			Run	6	79	55	177	57
		50-100 km^2	Pool	4	78	28	447	27
			Riffle	4	58	21	332	20
			Run	4	143	51	859	52
	1 to 3%	0-10 km^2	Pool	8	72	23	175	28
			Riffle	7	98	31	203	32
			Run	9	142	46	255	40
		10-50 km^2	Pool	9	68	22	225	24
			Riffle	13	137	44	400	43
			Run	8	105	34	313	33
	3 to 5%	0-10 km^2	Pool	4	14	9	18	11
			Riffle	3	21	14	24	14
			Run	6	120	77	130	75
Chakok	0 to 1%	0-10 km^2	Plane bed	7	93	30	174	29
			Pool	12	143	46	282	48
			Riffle	1	5	1	10	2
			Run	6	69	22	127	21
		50-100 km^2	Pool	4	114	32	717	33
			Riffle	0	0	--	0	--
			Run	3	245	68	1,462	67
	1 to 3%	0-10 km^2	Pool	7	55	18	115	18
			Riffle	8	109	35	245	38
			Run	12	144	47	276	43
		10-50 km^2	Pool	4	54	22	269	26
			Riffle	2	43	17	209	20
			Run	3	149	60	546	53

Table 12. Summary of depletion abundance estimates and model failures (total number of possible estimates in parentheses) in habitat units sampled with backpack electrofishing, minnow traps, and seines in 2011. Model Failure indicates an abundance estimate could not be calculated because depletion did not occur.

			Model Failures		
Species	Units Present	Valid Estimate	Minnow Trap	Electrofishing	Seine
Coho Salmon	74	57	8 (36)	8 (33)	1 (5)
Chinook Salmon	44	34	6 (28)	3 (6)	1 (10)
Dolly Varden	75	55	6 (34)	9 (34)	5 (7)
O. mykiss	44	22	13 (31)	2 (5)	7 (8)

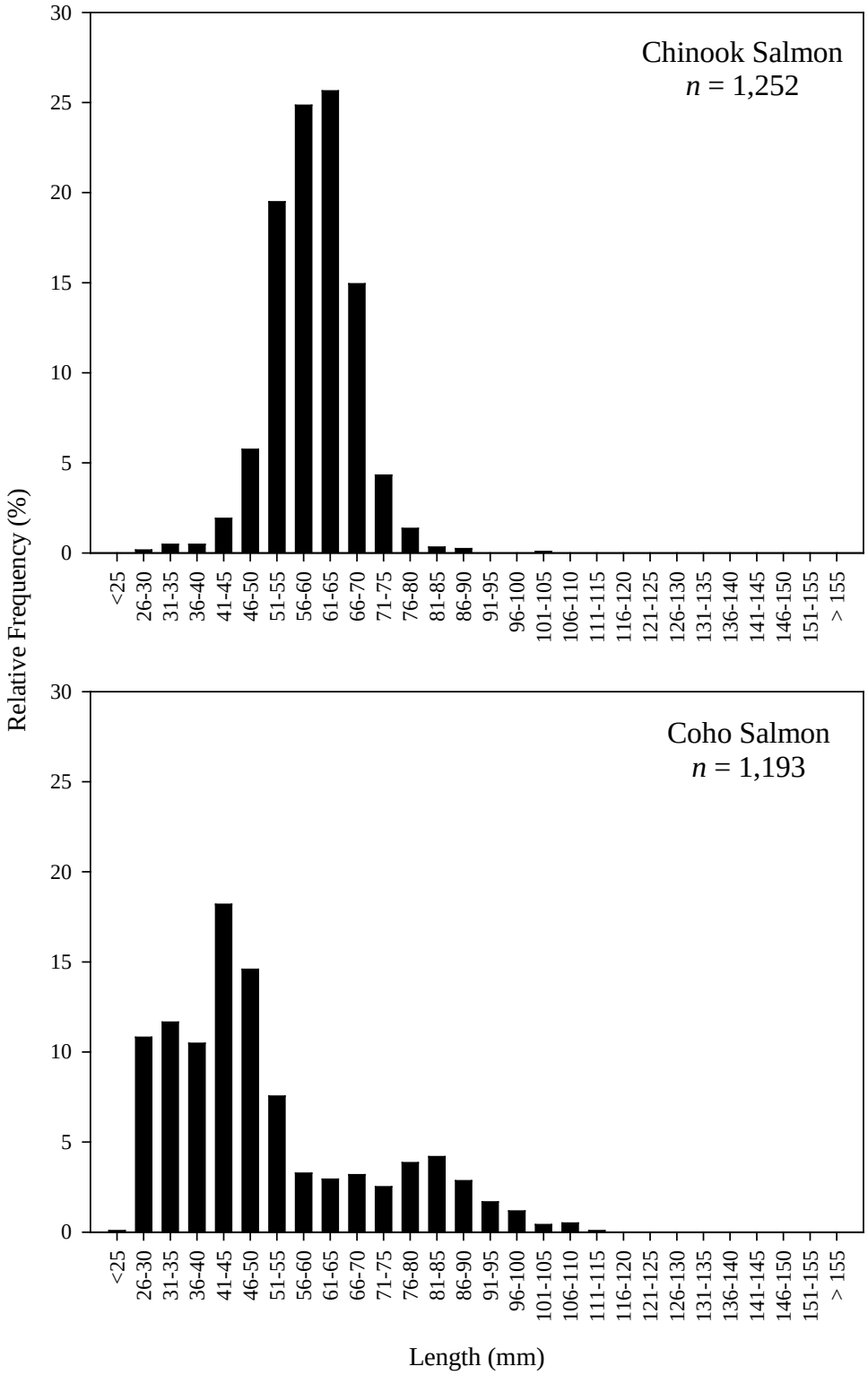

Figure 11. Length-frequency distribution of Chinook (top) and Coho (bottom) salmon sampled with seining, minnow traps and electrofishing in the Anchor River watershed, 2011.

165 mm (Figure 12). Length-frequency distributions for Dolly Varden and juvenile *O. mykiss* indicate we probably sampled at least three age classes in 2011.

Scales were collected from n = 220 Coho Salmon greater than 60 mm in length sampled using minnow traps, electrofishing, and seines from July 6 to September 14, 2011. Three ages were identified from scale samples (Figure 13); most fish greater than 70 mm FL were age 1, whereas most fish less than 70 mm FL were age 0. We did not collect scale samples from any fish less than 60 mm but assume most fish less than 60 mm were age 0. Based on this assumption, most juvenile Coho Salmon sampled in 2011 (Figure 11) were age 0.

Adult Escapement

We operated the ADF&G weir on the Anchor River using underwater video to monitor fish passage from August 1 to September 21, 2011. We counted n = 1,858 Coho Salmon passing the weir in August and September (Appendix B) and a total escapement of N = 1,866 included n = 8 fish that passed the weir in July (Carol Kerkvliet, ADF&G, personal communication). We counted n = 132 steelhead passing through the weir in August and September; none passed the weir in July (Carol Kerkvliet, ADF&G, personal communication). Other species observed at the Anchor River weir in August and September included Chinook (n = 96), Chum (n = 58), Pink (n = 1,210), and Sockeye (n = 41) salmon, and Dolly Varden (n = 529). Peaks in Coho Salmon passage corresponded with high flow freshets (Figure 14) and 90% of passage occurred prior to September 10 (Appendix B). Most steelhead passage occurred in early September, but were still observed passing the weir when it was pulled on September 21. Therefore, we did not count a portion of the steelhead run that entered the Anchor River after the weir was pulled. Steelhead passage occurred almost exclusively at night between 2100 and 0400 hours, but we did not observe a similar passage pattern for Coho Salmon (Figure 15).

A summary of daily water temperatures is presented in Appendix C, and a summary of mean daily stage height compared to historical data is presented in Appendix D.

Discussion

We were successful operating a rotary-screw trap on the Anchor River during 2011 to estimate Chinook and Coho salmon smolt abundance and migration timing. The trap operated continuously from May 18 through July 23, 2011. We were not able to operate the screw trap after July 23 because water levels and velocities were too low to spin the cone. Water levels from May to August in 2011 were lower compared to 2010 and to mean historical values (Appendix D).

Once estimated flows fell below 200 ft^3/s in late June (after Stratum 5), the cone typically rotated at less than 3 RPM and capture efficiencies for both species declined to less than 10% (Tables 5 and 6). Because most Coho Salmon smolts migrated past the trap prior to these declines in capture efficiency, the confidence interval width (8,728) for our smolt abundance estimate was relatively precise and within our stated objective (25% of the estimated abundance; Table 4). However, most Chinook Salmon were captured at the trap during the periods of low capture efficiency after Stratum 5 and the resulting confidence interval width (66,102) did not meet our objective of being within 25% of the estimated abundance (Table 3). This was expected because of low capture efficiencies. The sample size to achieve Objective 1 was developed assuming a

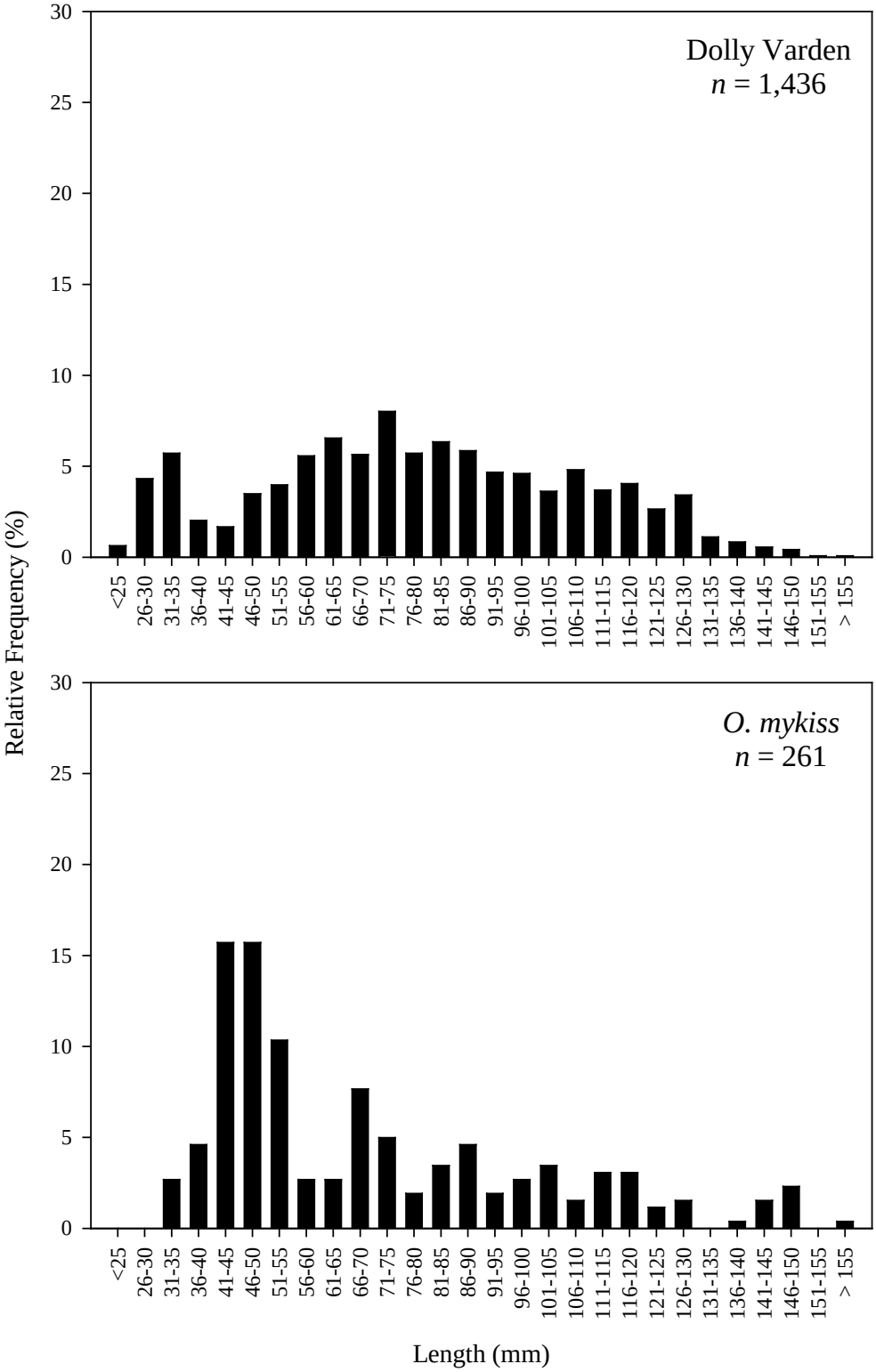

Figure 12. Length frequency distribution of Dolly Varden (top) and *O. mykiss* (bottom) sampled with seining, minnow traps and electrofishing in the Anchor River watershed, 2011.

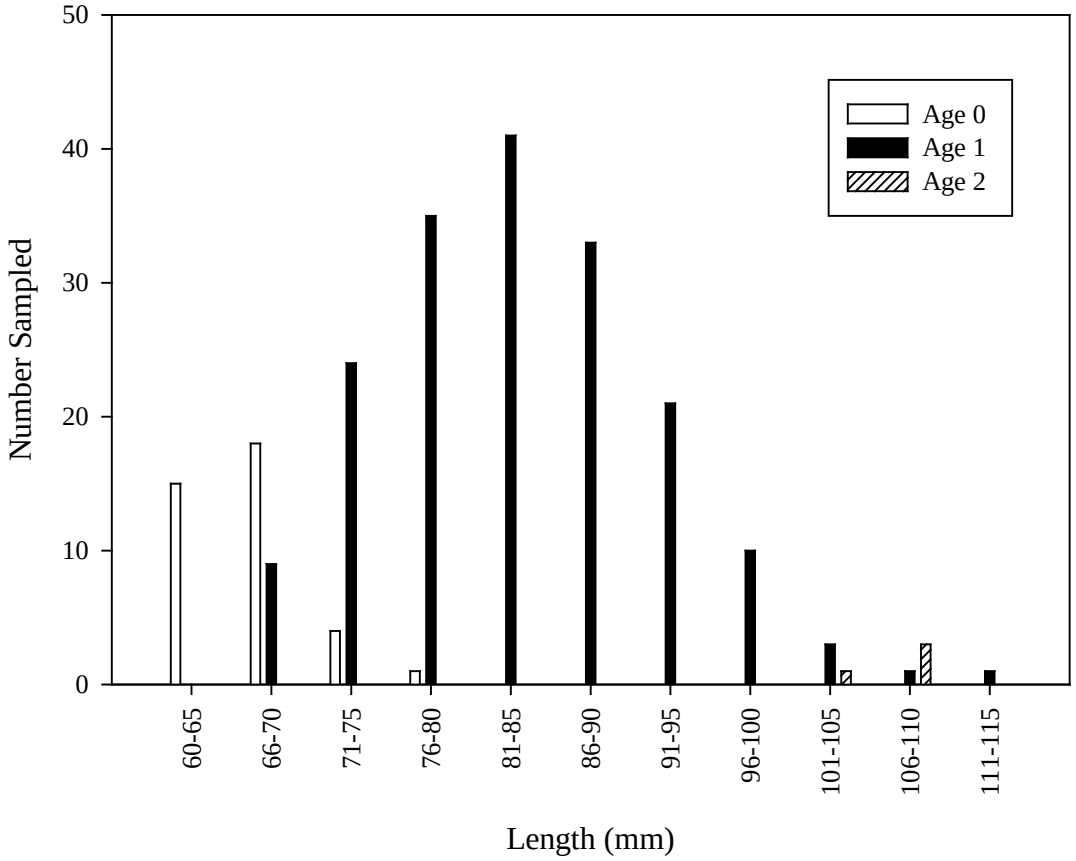

Figure 13. Length composition by age for juvenile Coho Salmon (> 60 mm FL) sampled throughout the Anchor River watershed between July 8 and September 14, 2011, using minnow traps, electrofishing, and seines.

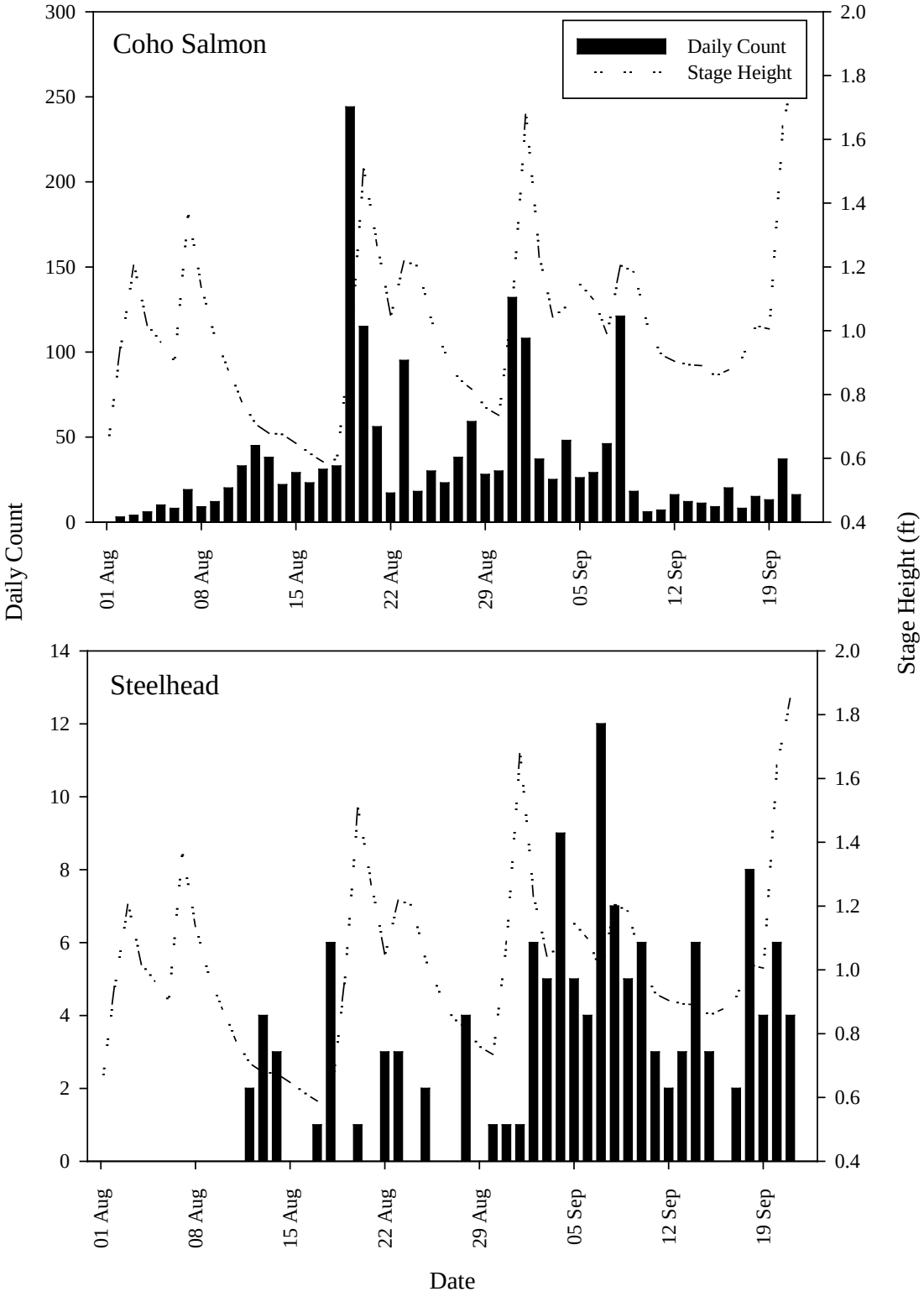

Figure 14. Daily passage of Coho Salmon (top) and steelhead (bottom) observed at the Anchor River weir in relation to stage height, 2011.

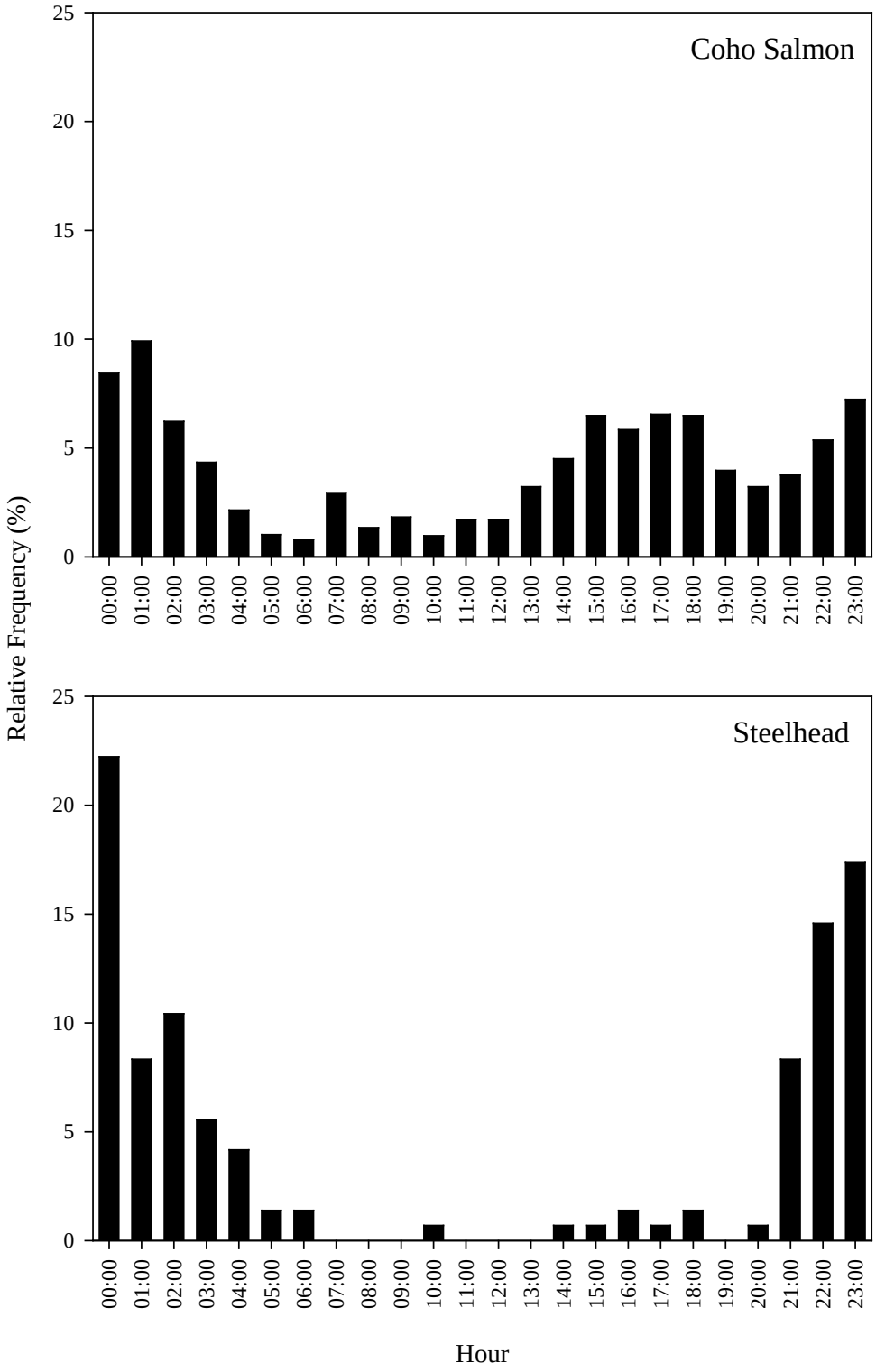

Figure 15. Hourly passage of Coho Salmon (top) and steelhead (bottom) observed at the Anchor River weir, 2011.

capture efficiency of 15%, whereas the overall capture efficiency for Chinook Salmon was only 6.8% and the capture efficiency for Chinook Salmon in Strata 6 – 9 was only 2.3% (Table 6). A larger weekly sample size of M_h = 760 would likely have allowed us to achieve our objective for confidence interval width, and additional measures to improve capture efficiency are discussed below.

Most mark-recapture assumptions for an unbiased Lincoln-Petersen estimate of smolt abundance following Carlson et al. (1998) were met for most strata. These assumptions included: 1) closed population; 2) all smolts have the same probability of being marked or all smolts have the same probability of being examined for marks; 3) constant capture probability; 4) marks are not lost between release and recovery; 5) all marked smolts are reported; and 6) all marked smolts released are either recovered or pass by the downstream capture site. Assumption 1 was probably met in most strata, and fish mortality observed during handling and marking was minimal (<1%) and was censored from the estimate. Our release site at the confluence of the North and South forks allowed marked fish to mix with the general smolt population prior to recapture (Assumption 2). Although the trap was not size selective for Coho Salmon, the length distributions for marked and unmarked Chinook Salmon were different – larger smolt were less likely to be recaptured (Figure 5). Thedinga et al. (1994) also observed some differences in trap efficiency based on smolt size for some species, but considered the overall effect on population estimates to be minimal.

Assumption 3 requires capture efficiency to be constant within each stratum. Many factors can influence trap efficiency including time of release and turbidity (Eskelin 2004), changing stream flows (Volkhardt et al. 2007), fish size and species (Thedinga et al. 1994; Volkhardt et al. 2007), and changes to how the trap is operated (e.g., moved to different positions, addition of screen panels). To address these factors, we used the same release site and released fish at or near dusk each day, we developed separate estimates for Chinook and Coho salmon, we tested for size selectivity, and did not change the screw trap location or operating pattern once fishing started on May 18.

The partial caudal fin-clips used as marks were clearly visible when recaptured at the screw trap and did not regenerate in the short time between release and recovery (Assumption 4). The crew was properly trained in fish handling and marking techniques and followed procedures to ensure all captured fish were examined for marks and all marks were reported (Assumption 5). We only marked and released fish classified as smolt or transitional, and nearly all marked smolts migrated past the screw trap during the same strata of release (Assumption 6).

Although fish were marked and released on a daily basis, it may not be appropriate to investigate relationships using daily capture efficiencies because not all marked fish moved past the screw trap immediately after release. Therefore, the number of fish available for capture upstream of the trap on any given day may have been greater than the number recently released. Most marked smolts migrated past the smolt trap shortly after release, but some fish were recaptured in a different stratum than released. Because of the relative low numbers of smolts (n = 2 Chinook Salmon and n = 1 Coho Salmon) exhibiting this behavior, we assume any bias associated with Assumption 6 is minimal because over 99% of all marked smolts passed the capture site within their tagging stratum. Thedinga et al. (1994) also noted most recaptures occurred shortly after release: 2-28% within one day and 90% within one week of release. Unique daily marks would allow for more detailed analysis and modeling of capture efficiencies and allow us to track fates of daily releases with more detail (Roper and Scarnecchia 2000), but is not practical with batch

marks. Uniquely-numbered tags such as passive-integrated transponder tags might be practical, but they were not feasible for this project because of available funding.

Capture efficiencies for Chinook and Coho salmon varied over the course of the season (Tables 5 and 6) and *G*-tests of independence (Sokal and Rohlf 1981) indicate capture efficiency data were not independent of tagging strata and should not be pooled ($P < 0.0001$ for both species). Because we used batch marks and not all fish were recaptured the day after release, we were unable to calculate true daily capture efficiencies and were therefore unable to test whether capture efficiencies were constant within each tagging stratum. Variable capture efficiencies within tagging strata can lead to bias, although Carlson et al. (1998) found minimal bias even though true capture efficiencies varied considerably within their sampling strata (e.g., from 10% to 35% in two of their five sampling periods). They recommend minimizing stratum length and maintaining discrete sampling periods of about one week. Volkhardt et al. (2007) also recommend strata durations between three days and one week.

Our low capture efficiencies for both species during low flows and apparent size selectivity for Chinook Salmon may be due to trap avoidance. Even though our trap was placed in the thalweg, fish may have had more time to detect and avoid the trap, thus reducing efficiency during low flow periods (Roper and Scarnecchia 2000). Roper and Scarnecchia (1996) also observed avoidance behavior of hatchery-reared Chinook Salmon smolts in areas of low to medium water velocity. Volkhardt et al. (2007) discuss the ability of larger downstream migrants to swim around the trap or back out of the mouth of the trap when velocities are low, and Thedinga et al. (1994) discuss the ability of larger migrants to avoid capture. Rayton (2006) recommends a cone rotation rate of 5 to 6 RPM to maximize capture of larger smolts, and in general we were unable to achieve this rate from early June through the end of the sampling period (Appendix A). In the future, screen panels or other methods to concentrate fish movement and increase water velocity (and thus cone RPM) would likely improve capture efficiency.

Predation may also have been a factor affecting capture probabilities during low flow periods, although this seems unlikely. Predators of Chinook and Coho salmon smolts in the Anchor River include adult Rainbow Trout and adult Dolly Varden, neither of which were captured in large numbers in our trap. Our strategy of holding fish in a live well at the release site to allow marked fish to recover and releasing fish at dusk was designed to minimize handling effects such that marked and unmarked fish mixed completely and are equally vulnerable to capture and predation. Finally, we would expect predation rates to be higher on smaller individuals, but the unequal length distributions of marked versus recaptured Chinook Salmon suggest larger individuals were less likely to be recaptured (Figure 5).

Predicting numbers of unmarked smolts for days in 2010 when the rotary-screw trap could not be safely operated because of high water involved extrapolating outside of the range of observed data and estimates should be viewed with caution. Estimates for unmarked Chinook Salmon smolts on July 14 ($n = 905$) and July 27 ($n = 711$) were the two highest days of passage, and the estimate of $n = 1{,}436$ unmarked Coho Salmon smolt on July 14 was also the highest passage day (Figure 9). These estimates for numbers of unmarked smolts for July 14 and 27, 2010, increased our overall abundance estimate for Coho Salmon smolts by 29% and for Chinook Salmon smolts by 9%, with subsequent changes to 90% confidence intervals (Table 8). Although we were unable to estimate numbers of unmarked Chinook and Coho salmon smolts when the rotary-screw trap was inoperable August 4-5, 2010, this likely had minimal effect on the overall

estimate because capture of both species at the trap declined considerably prior to August 5 (Figure 2 and Appendix B in Anderson and Stillwater Sciences 2011).

Estimating smolt numbers for days in 2010 when the trap could not be operated increased our overall abundance estimate by 29% (from 50,688 to 65,156; Table 8), but decreased our estimate of smolt-to-spawning adult return rate from 3.7% (90% C.I. range 3.4% to 4.0%) to 2.9% (90% C.I. range 2.6% to 3.2%). Regardless of which estimate we use for smolt abundance in 2010, our estimated smolt-to-spawning adult return rate of < 4.0% is at the low end of the range of observations for marine survival in other Coho Salmon populations in Alaska and the Pacific Northwest. Smolt-to-spawning adult return rate for Deep Creek, the adjacent drainage to the Anchor River on the lower Kenai Peninsula, ranged from 5% to 16% (8% to 21% marine survival rate) for 3 years when estimates were possible (Table 23 in Kerkvliet et al. 2013). Coho Salmon marine survival rates reported for other Pacific Northwest streams range from 0.5% to over 40% (Table 13). However, commercial, sport, and subsistence harvests can contribute greatly to overall mortality (over 80%; Beers 2001), and information is often not available to allow separation of fishing and natural mortality. On average, in-river sport harvest of Coho Salmon in the Anchor River accounts for over 30% of the total run (range 11-59%; Kerkvliet et al. 2013). In-river sport harvest of Coho Salmon in Deep Creek is also substantial and ranged from 23% to 57% between 1996 and 2001 (Kerkvliet et al. 2013).

Based on overall low numbers of juvenile fish captured and overall low mean densities of juvenile Chinook and Coho salmon throughout the Anchor River in 2010 (Anderson and Stillwater Sciences 2011), we increased overall effort and focused effort to include larger

Table 13. Comparison of Coho Salmon marine survival rate estimates throughout the Pacific Northwest and Alaska.

Stream	Location	Survival Estimate	Source
Porcupine Creek[a]	SE Alaska	4.5 - 6.5%	Thedinga (1986)
Slippery Creek[a]	SE Alaska	8.4%	Beers (2001)
Bear Lake[b]	SC Alaska	1.1 - 5.1%	McHenry (1981)
14 stocks[c]	British Columbia	0.5 - 23.1%	Labelle et al. (1997)
Black Creek[a]	British Columbia	3 - 20%	Bradford et al. (2000)
Thompson River[c]	British Columbia	< 5%	Bradford and Irvine (2000)
Rosewall Creek[b]	British Columbia	3.1 - 43.3%	Bilton et al. (1982)
Various hatcheries[b]	Oregon	0.1 - 11.0%	Nickelson and Lawson (1998)
Various hatcheries[b]	Pacific Northwest	0.9 - 6.2%	Coronado and Hilborn (1998)
Various streams[a]	Pacific Northwest	9.8%	Bradford (1995)

[a] = Natural production
[b] = Hatchery production
[c] = Combination of natural and hatchery production

streams (drainage area > 50 km^2) during 2011. Our resulting overall capture numbers for all species were higher in 2011 than 2010.

In general, juvenile Coho Salmon were observed at higher densities in smaller streams (0-10 km^2 drainage area), and juvenile Chinook Salmon and *O. mykiss* were observed at higher densities in larger (> 10 km^2 drainage area) streams (Tables 9 and 10). These larger habitat units may provide better rearing habitat for juvenile Chinook Salmon as they are typically found in larger main channel, higher-velocity areas compared to Coho Salmon (Murphy et al. 1989; Healey 1991). Also, most Chinook Salmon spawning likely occurs in the main-stem Anchor River and juveniles are not likely to migrate upstream into the smaller tributary streams in large numbers. Juvenile Chinook Salmon were more abundant in streams with gradients < 1% and none were observed in any habitat unit above 3% gradient. Coho Salmon were more broadly distributed among all slope classes but few were observed in gradients > 3% (Tables 9 and 10). Both species were found in pool and run habitats at higher densities than in riffles, although fewer riffles were sampled than other habitat types.

Most juvenile Coho Salmon sampled during summer and fall were age 0 whereas most smolt sampled at the rotary-screw trap were age 2, and most adults sampled at the Anchor River weir are age 2.1 (Kerkvliet and Booz 2012). This is similar to observations for Coho Salmon on the Alaska Peninsula by Anderson and Hetrick (2004) where most juvenile Coho Salmon sampled in summer and fall were age 0 but most returning adults were age 2.1. They suggested differential survival of the two juvenile age classes, at least in part related to size. Quinn and Petersen (1996) observed higher overwinter survival rates for larger juvenile Coho Salmon in the wild, and preliminary results from our overwinter survival work in Twitter Creek (Objective 3) indicate larger Chinook and Coho salmon have higher survival rates than smaller fish (U.S. Fish and Wildlife Service, unpublished data).

Mean relative density of juvenile Coho Salmon in pool habitats across all systems and slope classes for drainage areas < 10 km^2 was about 1.0 fish/m^2, which is similar to values used to model habitat limiting factors in Oregon streams (mean summer densities > 1.5 fish/m^2 in pool habitat; Nickelson 1998) at levels believed to represent fully seeded habitat for juvenile Coho Salmon in the Pacific Northwest (1.0 fish/m^2 in pools; Nickelson et al. 1992). Anderson and Hetrick (2004) also observed mean summer densities of juvenile Coho Salmon in pool habitats greater than 1.4 fish/m^2 during one year in streams on the Alaska Peninsula, although they observed lower densities (0.43 fish/m^2) during a second year. They attributed the lower densities during the second year of sampling to a low spawning escapement of adult Coho Salmon the previous year. Observed Coho Salmon densities in the Anchor River in 2010 were low following low adult escapement in 2009 (2,691 fish, the lowest recorded since monitoring began in 2004; Table 1), whereas the higher observed densities in 2011 followed an escapement of over 6,000 adults in 2010. The low escapement in 2009 may be below levels necessary to fully seed habitat in the Anchor River watershed. As Anderson and Stillwater Sciences (2011) noted, a larger spawning escapement of adult Coho Salmon in 2010 would likely lead to a more wide-spread distribution of adults and would also likely lead to higher juvenile densities in 2011.

By changing our protocols to add additional depletion passes as necessary for our minnow trap and electrofishing removal experiments, we were able to obtain a greater number of valid abundance estimates compared to 2010. Over 75% of removal experiments for juvenile Chinook and Coho salmon resulted in depletion in 2011 (Table 12) compared with only 11% and 52% for juvenile Chinook and Coho salmon, respectively, in 2010 (Anderson and Stillwater Sciences

2011). However, juvenile abundance estimates in 2011 should be interpreted with caution because the initial abundance of all species in nearly all habitat units was less than the minimum population size (N = 200) recommended by White et al. (1982) for effective sampling and reliable estimates.

Summary

We conducted field investigations from May 2010 to July 2012 to help parameterize and validate an application of the RIPPLE model in the Anchor River watershed. Through this project, we provided the first estimates of smolt abundance for Chinook and Coho salmon in the watershed, the first estimate of smolt-to-adult return rate for Anchor River Coho Salmon, sampled juvenile salmonids throughout the watershed using various capture methods, and operated a weir to count returning adults. The overwinter survival estimate objective, which will be reported elsewhere, also provided useful information to help parameterize the RIPPLE model. Following are several summary highlights of findings for both years.

- Streamflow conditions affected the operation of the rotary-screw trap both years. High water events caused problems with operations in 2010 whereas low water conditions led to operational problems in 2011.
- Nearly all smolt passage occurred at night during both years.
- Most Coho Salmon smolts < 95 mm FL were age 1 and most Coho Salmon smolts > 95 mm were age 2.
- Although most Coho Salmon smolt emigrating the Anchor River were age 2, most juvenile Coho Salmon sampled during summer and fall were age 0.
- Achieving depletion with minnow traps and electrofishing for juvenile salmonids was difficult, although we had better success in 2011 than 2010. Alternative models to estimate abundance may be appropriate because nearly all initial low population sizes in habitat units were < 200 fish.
- Seining was an effective sampling method for juvenile Chinook Salmon in larger habitat units, although block nets were difficult to maintain in deep, fast water.
- Coho Salmon juvenile densities in 2010 were low which may be a result of low adult returns in 2009. Most juvenile Coho Salmon < 70 mm FL we sampled were age 0.
- Our estimate for Coho Salmon smolt-to-returning adult survival was sensitive to estimates for missed smolt passage the previous year, although overall marine survival in 2011 was comparatively low regardless of the smolt estimate. The observed adult Coho Salmon through the weir was the lowest recorded to date.
- Most adult Coho Salmon upstream migration through the weir followed high water events during both years. Most adult steelhead upstream migration through the weir occurred at night during both years.

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References

Anderson, J. L., and N. J. Hetrick. 2004. Carrying capacity of habitats used seasonally by Coho Salmon in the Kametolook River, Alaska Peninsula National Wildlife Refuge, 2002-2003. U. S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Technical Report Number 73, King Salmon, Alaska.

Anderson, J. L., N. J. Hetrick, D. Spencer, J. P. Larson, and M. Santos. 2006. Design and performance of a digital video monitoring system incorporated in a V-shaped resistance board weir. U.S. Fish and Wildlife Service, King Salmon Fish and Wildlife Field Office, Alaska Fisheries Technical Report Number 91, King Salmon, Alaska.

Anderson, J. L., and Stillwater Sciences. 2011. Chinook and Coho salmon life history characteristics in the Anchor River watershed, Southcentral Alaska, 2010. U.S. Fish and Wildlife Service, Kenai Fish and Wildlife Field Office, Alaska Fisheries Data Series Number 2011-8, Soldotna, Alaska.

Beers, D. 2001. Production of Coho Salmon from Slippery Creek, 1999-2000. Alaska Department of Fish and Game, Fishery Data Series No. 01-15, Anchorage, Alaska.

Bilton, H. T., D. F. Alderdice, and J. T. Schnute. 1982. Influence of time and size at release of juvenile Coho Salmon (*Oncorhynchus kisutch*) on returns at maturity. Canadian Journal of Fisheries and Aquatic Sciences 39:426-447.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Groves. 1982. A system of naming habitat types in small streams with examples of habitat utilization by salmonids during low streamflow. Pages 62-73 in N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. Proceedings of a symposium held 28-30 October, 1981, Western Division of the American Fisheries Society, Portland, Oregon.

Bjorkstedt, E. P. 2005. DARR 2.0: Updated software for estimating abundance from stratified mark-recapture data. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-368, Santa Cruz, California.

Bjorkstedt, E. P. 2010. DARR 2.0.2: DARR for R. http://swfsc.noaa.gov/textblock.aspx?Division=FED&id=3346

Bradford, M. J. 1995. Comparative review of Pacific Salmon survival rates. Canadian Journal of Fisheries and Aquatic Sciences 52:1327-1338.

Bradford, M. J., and J. R. Irvine. 2000. Land use, fishing, climate change, and the decline of Thompson River, British Columbia, Coho Salmon. Canadian Journal of Fisheries and Aquatic Sciences 57:13-16.

Bradford, M. J., R. A. Myers, and J. R. Irvine. 2000. Reference points for Coho Salmon (*Oncorhynchus kisutch*) harvest rates and escapement goals based on freshwater production. Canadian Journal of Fisheries and Aquatic Sciences 57:677-686.

Bromaghin, J. F. 1993. Sample size determination for interval estimation of multinomial probabilities. The American Statistician 47:203-206.

Bryant, M. D. 2000. Estimating fish populations by removal methods with minnow traps in Southeast Alaska streams. North American Journal of Fisheries Management 20:923-930.

Bryant, M. D. 2009. Global climate change and potential effects on Pacific salmonids in freshwater ecosystems of southeast Alaska. Climatic Change 95:169-193.

Carlson, S. R., L. G. Coggins Jr., and C. O. Swanton. 1998. A simple stratified design for mark-recapture estimation of salmon smolt abundance. Alaska Fishery Research Bulletin 5:88-102.

CBFWA (Columbia Basin Fish and Wildlife Authority). 1999. PIT tag marking procedures manual, version 2.0. PIT tag Steering Committee, Portland, Oregon.

Coronado, C., and R. Hilborn. 1998. Spatial and temporal factors affecting survival in Coho Salmon (*Oncorhynchus kisutch*) in the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 55:2067-2077.

Curry, R. A., R. M. Hughes, M. E. McMaster, and D. J. Zafft. 2009. Coldwater fish in rivers. Pages 139-158 *in* S. A. Bonar, W. A. Hubert, and D. W. Willis, editors. Standard methods for sampling North American freshwater fishes. American Fisheries Society, Bethesda, Maryland.

Dalbey, S. R., T. E. McMahon, and W. Fredenberg. 1996. Effect of electrofishing pulse shape and electrofishing-induced spinal injury on long-term growth and survival of wild Rainbow Trout. North American Journal of Fisheries Management 16:560-569.

Downs, C. C., D. Horan, E. Morgan-Harris, and R. Jakubowski. 2006. Spawning demographics and juvenile dispersal of an adfluvial Bull Trout population in Trestle Creek, Idaho. North American Journal of Fisheries Management 26:190–200.

Eskelin, A. A. 2004. An assessment of trap efficiency to estimate Coho Salmon smolt abundance in a small Alaskan stream. Master's Thesis, University of Alaska-Fairbanks, Fairbanks, Alaska.

Ewing, R. D., M. D. Evenson, E. K. Birks, and A. R. Hemmingsen. 1984. Indices of parr-smolt transformation in juvenile Steelhead Trout (*Salmo gairdneri*) undergoing volitional release at Cole Rivers Hatchery, Oregon. Aquaculture 40:209-221.

Feyrer, F., T. Sommer, and W. Harrell. 2006. Importance of flood dynamics versus intrinsic physical habitat in structuring fish communities: evidence from two adjacent engineered floodplains on the Sacramento River, California. North American Journal of Fisheries Management 26:408–417.

Gates, K. S., and J. K. Boersma. 2009. Abundance and run timing of adult steelhead 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 Number 2009-2, Soldotna, Alaska.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.

Healey, M. C. 1991. Life history of Chinook Salmon (*Oncorhynchus tshawytscha*). Pages 311-393 *in* C. Groot and L. Margolis, editors. Pacific Salmon life histories. University of British Columbia Press, Vancouver, British Columbia.

Jearld, A. 1983. Age determination. Pages 301- 324 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Johnson, J., and K. Klein. 2009. Catalog of waters important for spawning, rearing, or migration of anadromous fishes – Southcentral Region, Effective June 1, 2009. Alaska Department of Fish and Game, Special Publication No. 09-03, Anchorage, Alaska.

Kennen, J. G., S. J. Wisniewski, and N. H. Ringler. 1994. Application and modification of an auger trap to quantify emigrating fishes in Lake Ontario tributaries. North American Journal of Fisheries Management 14:828–836.

Kerkvliet, C. M., and M. D. Booz. 2012. Anchor River Chinook and Coho salmon escapement, 2009. Alaska Department of Fish and Game, Fishery Data Series No. 12-07, Anchorage, Alaska.

Kerkvliet, C. M., M. D. Booz, and B. J. Failor. 2013. Recreational fisheries in the Lower Cook Inlet Management Area, 2011-2013, with updates for 2010. Alaska Department of Fish and Game, Fishery Management Report No. 13-42, Anchorage, Alaska.

Kerkvliet, C. M., D. L. Burwen, and R. N. Begich. 2008. Anchor River 2003 and 2004 Chinook Salmon and 2004 Coho Salmon escapement. Alaska Department of Fish and Game, Fishery Data Series No. 08-06, Anchorage, Alaska.

Kyle, R. E., and T. P. Brabets. 2001. Water temperature of streams in the Cook Inlet Basin, Alaska, and implications of climate change. U. S. Geological Survey, Water-Resources Investigations Report 01-4109, Anchorage, Alaska.

Labelle, M., C. J. Walters, and B. Riddell. 1997. Ocean survival and exploitation of Coho Salmon (*Oncorhynchus kisutch*) stocks from the east coast of Vancouver Island, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 54:1433-1449.

Mauger, S. 2005. Lower Kenai Peninsula's salmon streams: annual water quality assessment, July 2004 – September 2005. Cook Inletkeeper, Homer, Alaska.

McHenry, E. T. 1981. Coho Salmon studies in the Resurrection Bay area. Sport Fish Studies, Volume 22, Alaska Department of Fish and Game, Juneau, Alaska.

Miller, B. A., and S. Sadro. 2003. Residence time and seasonal movements of juvenile Coho Salmon in the ecotone and lower estuary of Winchester Creek, South Slough, Oregon. Transactions of the American Fisheries Society 132:546–559.

Mobrand, L. E., J. A. Lichatowich, L. C. Lestelle, and T. S. Vogel. 1997. An approach to describing ecosystem performance "through the eyes of salmon". Canadian Journal of Fisheries and Aquatic Sciences 54:2964-2973.

Montgomery, D. R., and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109:596-611.

Mosher, K. H. 1968. Photographic atlas of Sockeye Salmon scales. Fishery Bulletin 67:243-280.

Murphy, M. L., J. Heifetz, J. F. Thedinga, S. W. Johnson, and K. V. Koski. 1989. Habitat utilization by juvenile Pacific Salmon in the glacial Taku River, Southeast Alaska. Canadian Journal of Fisheries and Aquatic Sciences 46:1677-1685.

Nickelson, T. E. 1998. A habitat-based assessment of Coho Salmon production potential and spawner escapement needs for Oregon coastal streams. Oregon Department of Fish and Wildlife Information Reports Number 98-4, Portland, Oregon.

Nickelson, T. E., and P. W. Lawson. 1998. Population viability of Coho Salmon, *Oncorhynchus kisutch*, in Oregon coastal basins: application of a habitat-based life cycle model. Canadian Journal of Fisheries and Aquatic Sciences 55:2383-2392.

Nickelson, T. E., Rodgers, J. D., S. L. Johnson, and M. F. Solazzi. 1992. Seasonal changes in habitat use by juvenile Coho Salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 49:783-789.

Overton, C. K., S. P. Wollrab, B. C. Roberts, and M. A. Radko. 1997. R1/R4 (Northern/Intermountain Regions) fish and fish habitat standard inventory procedures handbook. USDA Forest Service, General Technical Report INT-GTR-346, Ogden, Utah.

Pollard, W. R., G. F. Hartman, C. Groot, and P. Edgell. 1997. Field identification of coastal juvenile salmonids. Harbour Publishing, Madeira Park, British Columbia.

Pollock, K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107:1-97.

Quinn, T. P., and N. P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile Coho Salmon (Oncorhynchus kisutch) in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53:1555-1564.

Rayton, M. D. 2006. Field manual, Okanogan Basin monitoring and evaluation program, rotary screw trap protocols. Colville Confederated Tribes, Coulee Dam, Washington.

Reynolds, J. B. 1996. Electrofishing. Pages 221–253 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Reynolds, L., A. T. Herlihy, P. R. Kaufmann, S. V. Gregory, and R. M. Hughes. 2003. Electrofishing effort requirements for assessing species richness and biotic integrity in western Oregon streams. North American Journal of Fisheries Management 23:450-461.

Richter, A., and S. A. Kolmes. 2005. Maximum temperature limits for Chinook, Coho, and Chum salmon, and Steelhead Trout in the Pacific Northwest. Reviews in Fisheries Science 13:23-49.

Riley, S. C., and K. D. Fausch. 1992. Underestimation of trout population size by maximum-likelihood removal estimates in small streams. North American Journal of Fisheries Management 12:768-776.

Roper, B. B., and D. L. Scarnecchia. 1996. A comparison of wild and hatchery-reared age-0 Chinook Salmon trap efficiencies. North American Journal of Fisheries Management 16:214-217.

Roper, B. B., and D. L. Scarnecchia. 1999. Emigration of age-0 Chinook Salmon (*Oncorhynchus tshawytscha)* smolts from the upper South Umpqua River basin, Oregon, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 56:939-946.

Roper, B. B., and D. L. Scarnecchia. 2000. Key strategies for estimating population sizes of emigrating salmon smolts with a single trap. Rivers 7:77-88.

Ross, D. W., G. E. Daterman, J. L. Boughton, and T. M. Quigley. 2001. Forest health restoration in south-central Alaska: a problem analysis. USDA Forest Service, General Technical Report PNW-GTR-523, Portland, Oregon.

Sandercock, F. K. 1991. Life history of Coho Salmon (*Oncorhynchus kisutch*). Pages 395-446 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia.

Schoettger, R. A., and A. M. Julin. 1967. Efficacy of MS-222 as an anesthetic on four salmonids. United States Bureau of Sports Fisheries and Wildlife Investigations in Fish Control No 13, Washington, D. C.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, second edition. Macmillan, New York.

Seelbach, P. W., R. N. Lockwood, and G. R. Alexander. 1985. A modified incline-screen trap for catching salmon in large rivers. North American Journal of Fisheries Management 5:494-498.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry, second edition. W. H. Freeman and Company, New York, New York.

Steinhorst, K., Y. Wu, B. Dennis, and P. Kline. 2004. Confidence intervals for fish out-migration estimates using stratified trap efficiency methods. Journal of Agricultural, Biological, and Environmental Statistics 9:284-299.

Stillwater Sciences. 2009. RIPPLE case study: Coho Salmon enhancement, Rock Creek, Oregon. Stillwater Sciences, Arcata, California.

Strahler, A. N. 1952. Dynamic basis of geomorphology. Geological Society of America Bulletin 63:923-938.

Sykes, G. E., C. J. Johnson, and J. M. Shrimpton. 2009. Temperature and flow effects on migration timing of Chinook Salmon smolts. Transactions of the American Fisheries Society 138:1252–1265.

Szarzi, N. J., C. M. Kerkvliet, C. E. Stock, and M. D. Booz. 2007. Recreational fisheries in the Lower Cook Inlet Management Area, 2005-2007, with updates for 2004. Alaska Department of Fish and Game, Fishery Management Report No. 07-55, Anchorage, Alaska.

Thedinga, J. F. 1986. Life history of Coho Salmon in Southeastern Alaska. Pages 100-102 *in* R. C. Minard, Editor. Proceedings of the Bristol Bay Coho Salmon workshop. Bristol Bay Data Report No. 86-1, Alaska Department of Fish and Game, Division of Commercial Fisheries, Dillingham, Alaska.

Thedinga, J. F., M. L. Murphy, S. W. Johnson, J. M. Lorenz, and K. V. Koski. 1994. Determination of salmonid smolt yield with rotary-screw traps in the Situk River, Alaska, to predict effects of glacial flooding. North American Journal of Fisheries Management 14:837-851.

USFWS (U. S. Fish and Wildlife Service). 2004. Electrofishing. Chapter 6, part 241. Safety operations, occupational safety and health. USFWS, Washington, D.C.

Venditti, D., A. Kohler, C. Bretz, N. Brindza, J. Lockhart, A. Brimmer, and K. Apperson. 2006. Idaho Supplementation Studies; Brood Year 2003 Cooperative Report. 2003-2005 Progress Report for Project No. 198909800 (et al.), BPA Report DOE/BP-00006630-6, Portland, Oregon.

Viola, A. E., and M. L. Shuck. 1995. A method to reduce the abundance of residual hatchery steelhead in rivers. North American Journal of Fisheries Management 15:488-493.

Volkhardt, G. C., S. L. Johnson, B. A. Miller, T. E. Nickelson, and D. E. Seiler. 2007. Rotary screw traps and inclined plane screen traps. Pages 235-266 *in* D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X Augerot, T. A. O'Neil, and T. N. Pearsons. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Wedemeyer, G. A., R. L. Saunders, and W. C. Clarke. 1980. Environmental factors affecting smoltification and early marine survival of anadromous salmonids. Marine Fisheries Review 42:1-14.

White, G. C., D. R. Anderson, K. P. Burnham, and D. L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory, Los Alamos, New Mexico.

Appendix A. Summary of rotary-screw trap operation and capture on the Anchor River, 2011, where *u* is the number of unmarked smolts captured, *M* is the number of marked smolts released, and *m* is the number of marked smolts recaptured. The "Other" category for Dolly Varden and *O. mykiss* includes parr and adults.

			Chinook Salmon				Coho Salmon				Dolly Varden		*O. mykiss*		
Stratum	Date	Hours Fished	*u*	*M*	*m*	Parr	*u*	*M*	*m*	Parr	Smolt	Other	Smolt	Other	Cone RPM
1	18-May	9.4	7	0	0	0	0	0	0	0	166	0	0	0	7
1	19-May	24	14	0	0	1	2	0	0	0	878	0	0	2	7
1	20-May	22	13	0	0	0	3	0	0	0	1,880	1	0	0	6.75
1	21-May	24	6	5	1	0	5	5	1	0	1,424	0	0	0	6.5
1	22-May	24	13	12	3	0	4	4	1	0	855	0	0	1	7
1	23-May	24	6	6	1	0	2	2	1	1	1,477	0	0	1	6
1	24-May	24	6	6	1	0	3	3	1	0	928	0	0	1	6
1	25-May	24	2	2	0	0	10	10	4	1	1,425	0	0	0	6
1	26-May	24	1	0	0	0	11	11	5	0	1,340	0	0	0	6
1	27-May	24	0	0	1	0	24	24	11	0	1,215	0	0	0	6.5
1	28-May	24	1	1	0	0	23	23	5	0	1,221	0	2	0	5.5
2	29-May	24	2	2	0	0	48	44	18	0	839	0	0	0	5.5
2	30-May	24	0	0	0	0	35	34	4	0	904	0	1	0	5
2	31-May	13	1	1	0	0	46	45	8	1	673	1	1	0	5
2	1-Jun	24	3	3	0	0	73	44	20	0	457	0	0	0	5.75
2	2-Jun	24	3	3	0	0	128	45	9	0	329	0	1	0	5
2	3-Jun	24	1	0	0	0	130	45	14	0	300	0	3	0	5
2	4-Jun	24	1	1	0	0	161	45	9	0	210	0	0	0	5
3	5-Jun	24	4	1	0	0	271	45	10	0	205	0	0	1	5
3	6-Jun	24	16	16	4	0	201	45	16	5	127	0	2	0	5
3	7-Jun	24	3	3	0	0	170	45	5	0	123	0	0	0	4.75
3	8-Jun	24	4	4	0	0	234	45	5	1	88	0	0	1	4.5
3	9-Jun	24	0	0	0	0	181	45	2	0	54	0	0	1	4.5
3	10-Jun	24	10	9	1	0	155	45	8	1	43	0	0	0	4.5
3	11-Jun	24	9	4	0	0	134	45	4	0	40	0	0	0	4.25
4	12-Jun	24	16	16	2	0	171	45	5	0	29	0	1	0	4.5
4	13-Jun	24	20	19	0	0	89	45	3	1	16	0	0	1	4.25
4	14-Jun	24	11	10	1	3	91	45	2	0	16	0	0	0	4.25
4	15-Jun	24	27	18	3	0	177	45	7	0	18	0	1	0	4
4	16-Jun	24	194	45	5	2	1,376	45	12	6	20	0	0	2	6.75
4	17-Jun	24	74	45	17	0	535	45	6	13	6	0	0	1	5
4	18-Jun	24	43	43	9	0	202	45	10	3	11	0	2	0	4.75

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Appendix A. continued.

			Chinook Salmon				Coho Salmon				Dolly Varden		*O. mykiss*		
Stratum	Date	Hours Fished	*u*	*M*	*m*	Parr	*u*	*M*	*m*	Parr	Smolt	Other	Smolt	Other	Cone RPM
5	19-Jun	24	55	45	5	1	123	45	4	1	5	0	1	0	3.75
5	20-Jun	24	39	39	14	2	86	45	10	2	3	0	0	0	3.75
5	21-Jun	24	71	45	12	2	153	45	8	0	3	1	2	0	3.5
5	22-Jun	24	35	35	4	0	116	45	7	0	1	1	3	0	3
5	23-Jun	24	88	45	2	0	124	45	4	1	1	0	6	0	2.75
5	24-Jun	24	132	45	1	4	126	43	0	0	2	0	10	0	2.5
5	25-Jun	24	116	45	4	6	132	45	9	1	2	0	5	0	2.5
6	26-Jun	24	353	45	4	6	294	45	4	0	4	0	11	2	3.5
6	27-Jun	24	233	45	5	6	165	45	3	0	1	0	6	0	2.75
6	28-Jun	24	176	45	0	5	139	45	1	0	0	0	6	0	2.25
6	29-Jun	24	141	45	1	4	107	45	1	0	1	0	13	2	3
6	30-Jun	24	108	45	0	15	61	45	1	4	2	0	16	0	2.3
6	1-Jul	24	163	45	2	2	37	36	3	1	3	0	20	0	2
6	2-Jul	24	228	45	0	74	44	25	0	0	2	0	17	0	1.75
7	3-Jul	24	644	45	3	27	63	45	8	41	5	0	65	0	4.25
7	4-Jul	24	321	45	0	6	19	17	1	9	2	0	33	0	3
7	5-Jul	24	288	45	0	22	19	17	1	0	1	0	37	1	3
7	6-Jul	24	168	45	1	13	10	10	2	1	4	1	35	3	2.5
7	7-Jul	24	141	45	0	3	5	5	0	0	1	0	35	0	1.5
7	8-Jul	24	286	45	1	9	40	40	1	3	5	0	42	1	2.25
7	9-Jul	24	214	45	3	33	30	29	3	5	4	2	39	3	2.25
8	10-Jul	24	162	45	0	32	18	18	1	2	2	2	21	4	2.25
8	11-Jul	24	154	45	2	29	6	6	0	0	2	0	29	4	2
8	12-Jul	24	133	45	1	36	12	11	1	0	0	5	29	8	2.25
8	13-Jul	24	228	45	1	63	19	18	2	6	0	4	39	6	2.5
8	14-Jul	24	107	45	0	19	16	16	0	0	0	1	23	7	2.25
8	15-Jul	24	102	45	0	8	6	6	0	0	1	0	15	3	1.75
8	16-Jul	24	36	34	0	18	3	3	1	1	2	0	4	6	1.25
9	17-Jul	24	29	25	1	1	3	3	0	0	1	0	7	1	1
9	18-Jul	24	86	45	0	27	2	2	0	0	0	1	7	5	2
9	19-Jul	24	71	45	1	20	2	2	0	0	0	3	11	6	1.25
9	20-Jul	24	36	28	0	1	0	0	0	0	0	1	7	3	0.75
9	21-Jul	24	20	16	0	2	0	0	0	0	0	0	2	7	1.25
9	22-Jul	24	66	45	0	4	2	2	0	0	0	3	6	3	1
9	23-Jul	24	19	0	0	5	2	0	0	0	0	1	2	19	1
Total:			5,760	1,712	117	511	6,679	1,863	282	111	17,377	28	618	106	

Appendix B. Daily passage and percent cumulative escapement of Coho Salmon and steelhead, and daily passage of Dolly Varden (DV) and Chinook (CK), Chum (CM), Pink (PK), and Sockeye (SE) salmon at the Anchor River weir, August 1 – September 21, 2011.

	Coho Salmon		Steelhead		DV	CK	CM	PK	SE
Date	Daily	Cum (%)	Daily	Cum (%)	Daily	Daily	Daily	Daily	Daily
1-Aug	0	0.0	0	0.0	0	2	0	29	0
2-Aug	3	0.2	0	0.0	22	17	0	32	1
3-Aug	4	0.4	0	0.0	66	14	0	19	0
4-Aug	6	0.7	0	0.0	36	7	0	27	2
5-Aug	10	1.2	0	0.0	71	11	0	34	3
6-Aug	8	1.7	0	0.0	64	7	1	27	1
7-Aug	19	2.7	0	0.0	30	8	0	57	0
8-Aug	9	3.2	0	0.0	11	12	0	14	0
9-Aug	12	3.8	0	0.0	35	2	0	29	0
10-Aug	20	4.9	0	0.0	28	0	0	31	0
11-Aug	33	6.7	0	0.0	31	4	2	33	0
12-Aug	45	9.1	2	1.5	13	1	0	19	1
13-Aug	38	11.1	4	4.5	13	4	0	21	0
14-Aug	22	12.3	3	6.8	21	4	0	22	1
15-Aug	29	13.9	0	6.8	18	1	7	26	0
16-Aug	23	15.1	0	6.8	19	0	1	12	0
17-Aug	31	16.8	1	7.6	19	0	0	7	1
18-Aug	33	18.6	6	12.1	10	1	0	7	0
19-Aug	244	31.7	0	12.1	5	0	0	94	1
20-Aug	115	37.9	1	12.9	3	0	1	59	0
21-Aug	56	40.9	0	12.9	6	1	1	70	0
22-Aug	17	41.8	3	15.2	0	0	0	44	0
23-Aug	95	46.9	3	17.4	1	0	6	49	2
24-Aug	18	47.9	0	17.4	0	0	2	5	2
25-Aug	30	49.5	2	18.9	0	0	7	11	0
26-Aug	23	50.8	0	18.9	0	0	0	22	1
27-Aug	38	52.8	0	18.9	0	0	2	21	0
28-Aug	59	56.0	4	22.0	0	0	3	28	4
29-Aug	28	57.5	0	22.0	0	0	2	12	0
30-Aug	30	59.1	1	22.7	0	0	2	19	1
31-Aug	132	66.2	1	23.5	0	0	1	68	4
1-Sep	108	72.0	1	24.2	0	0	8	41	0
2-Sep	37	74.0	6	28.8	1	0	1	23	2
3-Sep	25	75.3	5	32.6	1	0	0	9	0
4-Sep	48	77.9	9	39.4	1	0	0	9	0

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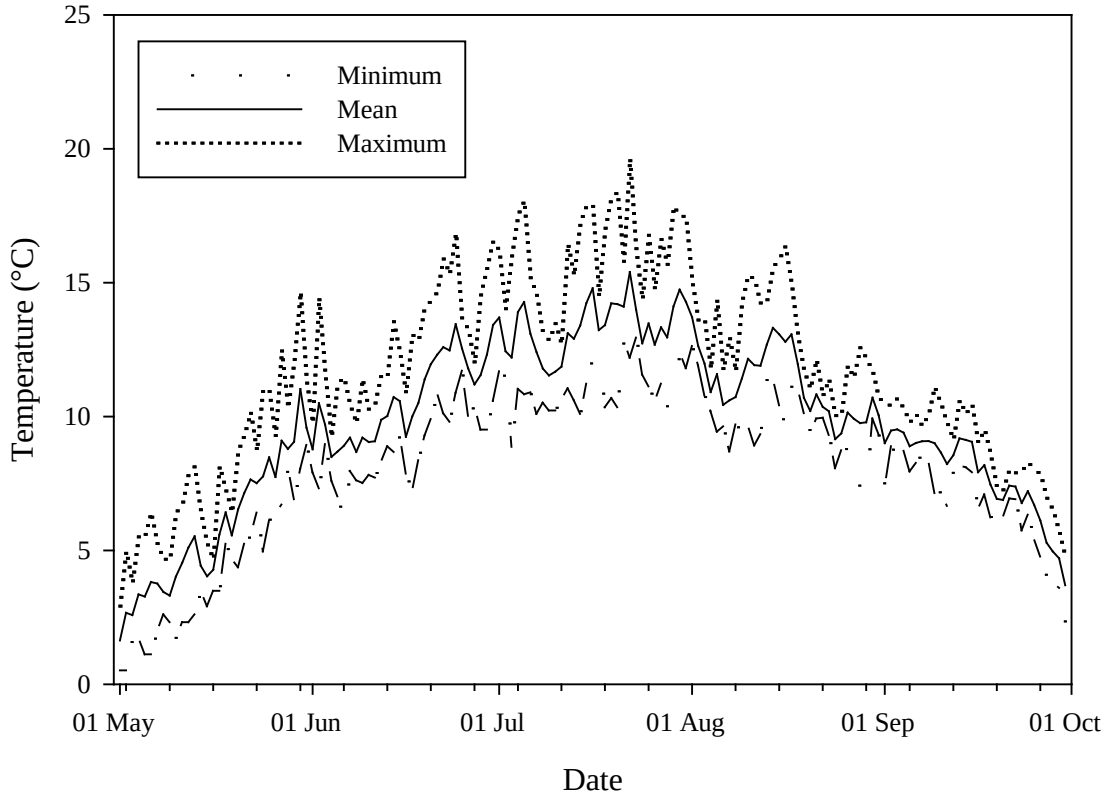
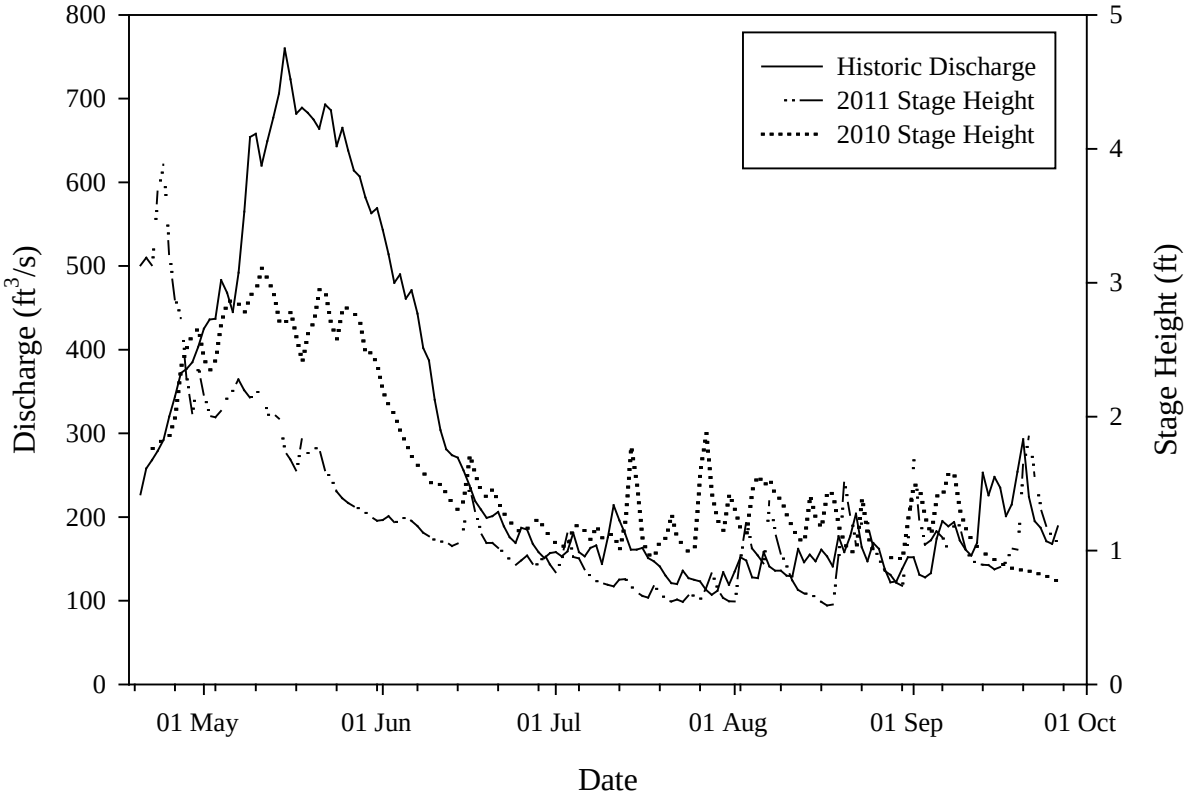
Appendix B. continued.

	Coho Salmon		Steelhead		DV	CK	CM	PK	SE
Date	Daily	Cum (%)	Daily	Cum (%)	Daily	Daily	Daily	Daily	Daily
5-Sep	26	79.3	5	43.2	0	0	1	13	1
6-Sep	29	80.9	4	46.2	0	0	0	19	1
7-Sep	46	83.4	12	55.3	0	0	1	25	2
8-Sep	121	89.9	7	60.6	0	0	0	39	2
9-Sep	18	90.9	5	64.4	0	0	1	16	0
10-Sep	6	91.2	6	68.9	0	0	0	8	1
11-Sep	7	91.6	3	71.2	0	0	0	13	1
12-Sep	16	92.4	2	72.7	0	0	1	9	0
13-Sep	12	93.1	3	75.0	0	0	1	14	0
14-Sep	11	93.6	6	79.5	0	0	1	10	3
15-Sep	9	94.1	3	81.8	4	0	0	3	2
16-Sep	20	95.2	0	81.8	0	0	0	1	0
17-Sep	8	95.6	2	83.3	0	0	0	6	0
18-Sep	15	96.4	8	89.4	0	0	1	1	1
19-Sep	13	97.1	4	92.4	0	0	2	0	0
20-Sep	37	99.1	6	97.0	0	0	1	0	0
21-Sep	16	100.0	4	100.0	0	0	1	3	0
Total:	**1,858**		**132**		**529**	**96**	**58**	**1,210**	**41**



Appendix C. Summary of water temperatures observed at the Anchor River below the confluence of the North and South forks, May 1 – September 30, 2011. Data provided by Cook Inletkeeper.



Appendix D. Comparison of mean daily stage height observed in 2010 and 2011 with historic mean daily discharge for the Anchor River. Unpublished data from U. S. Geological Survey: http://waterdata.usgs.gov/nwis/nwisman/?site_no=15239900