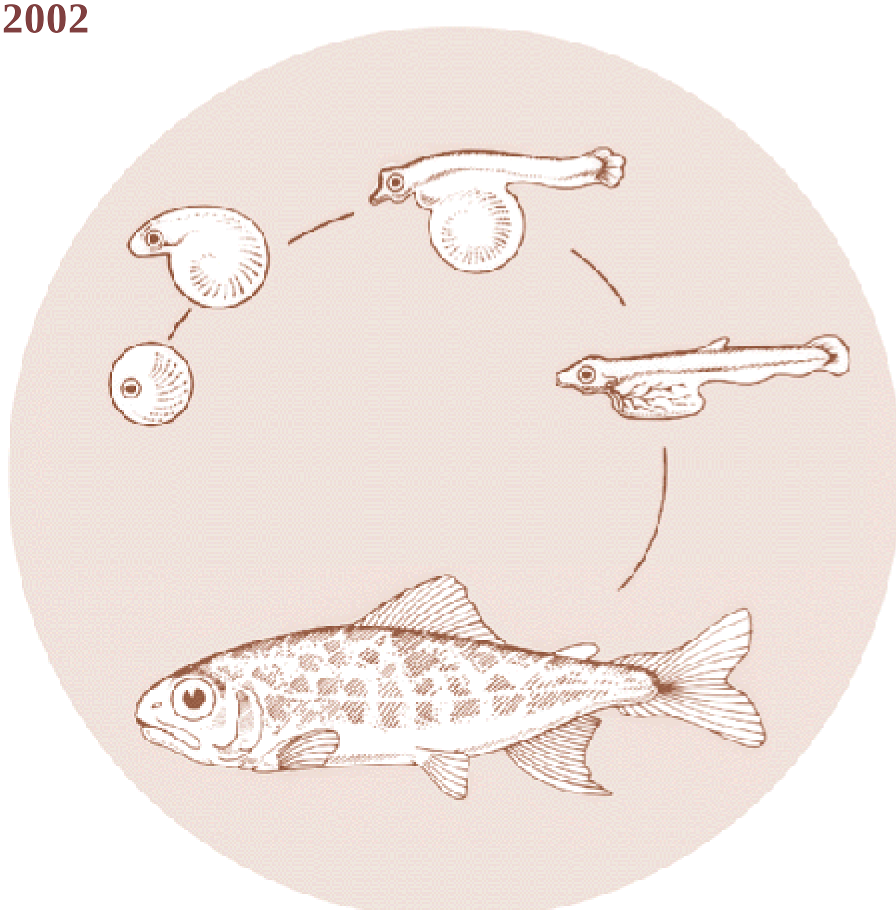
Population Estimates for Chum Salmon Spawning in the Mainstem Columbia River

Technical Report
2002



DOE/BP-00007373-3

November 2003

This Document should be cited as follows:

Rawding, Dan, Todd Hillson, ''Population Estimates for Chum Salmon Spawning in the Mainstem Columbia River'', Project No. 2001-05300, 47 electronic pages, (BPA Report DOE/BP-00007373-3)

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This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA.

Population Estimates for Chum Salmon Spawning in the Mainstem Columbia River, 2002

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Project Number 2001-053-00
Contract Number 00007373

November 2003

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Abstract

Accurate and precise population estimates of chum salmon (*Oncorhynchus keta*) spawning in the mainstem Columbia River are needed to provide a basis for informed water allocation decisions, to determine the status of chum salmon listed under the Endangered Species Act, and to evaluate the contribution of the Duncan Creek re-introduction program to mainstem spawners. Currently, mark-recapture experiments using the Jolly-Seber model provide the only framework for this type of estimation. In 2002, a study was initiated to estimate mainstem Columbia River chum salmon populations using seining data collected while capturing broodstock as part of the Duncan Creek re-introduction. The five assumptions of the Jolly-Seber model were examined using hypothesis testing within a statistical framework, including goodness of fit tests and secondary experiments. We used POPAN 6, an integrated computer system for the analysis of capture-recapture data, to obtain maximum likelihood estimates of standard model parameters, derived estimates, and their precision. A more parsimonious final model was selected using Akaike Information Criteria. Final chum salmon escapement estimates and (standard error) from seining data for the Ives Island, Multnomah, and I-205 sites are 3,179 (150), 1,269 (216), and 3,468 (180), respectively. The Ives Island estimate is likely lower than the total escapement because only the largest two of four spawning sites were sampled. The accuracy and precision of these estimates would improve if seining was conducted twice per week instead of weekly, and by incorporating carcass recoveries into the analysis.

Population estimates derived from seining mark-recapture data were compared to those obtained using the current mainstem Columbia River salmon escapement methodologies. The Jolly-Seber population estimate from carcass tagging in the Ives Island area was 4,232 adults with a standard error of 79. This population estimate appears reasonable and precise but batch marks and lack of secondary studies made it difficult to test Jolly-Seber assumptions, necessary for unbiased estimates. We recommend that individual tags be applied to carcasses to provide a statistical basis for goodness of fit tests and ultimately model selection. Secondary or double marks should be applied to assess tag loss and male and female chum salmon carcasses should be enumerated seperately. Carcass tagging population estimates at the two other sites were biased low due to limited sampling. The Area-Under-the-Curve escapement estimates at all three sites were 36% to 76% of Jolly-Seber estimates. Area-Under-the Curve estimates are likely biased low because previous assumptions that observer efficiency is 100% and residence time is 10 days proved incorrect. If managers continue to rely on Area-Under-the-Curve to estimate mainstem Columbia River spawners, a methodology is provided to develop annual estimates of observer efficiency and residence time, and to incorporate uncertainty into the Area-Under-the-Curve escapement estimate.

Introduction

In 1999, the National Marine Fisheries Service (NMFS) listed Columbia River chum salmon (*Oncorhynchus keta*) as a threatened species under the Endangered Species Act (ESA)(64 FR 14508). The Columbia River Chum Salmon Evolutionary Significant Unit (ESU) currently extends from the mouth of the Columbia River up to The Dalles Dam (Johnson et al. 1997). The NMFS Technical Recovery Team (TRT) identified nineteen stocks within this ESU, including two that currently rely on successful spawning in the mainstem Columbia River for persistence (Myers et al. 2002). The Lower Gorge stock uses the mainstem Columbia River and its tributaries from Bonneville Dam downstream to the Washougal River. This population has at least five semi-isolated groups spawning in Hamilton Creek, Hardy Creek, Duncan Creek, mainstem Columbia River near Ives Island, and mainstem Columbia River near Multnomah Creek. The Washougal stock spawns in the lower Washougal River and in the mainstem Columbia River just upstream of the I-205 Bridge. To assess the status of these and other chum salmon stocks accurate and precise population estimates are needed.

The Bonneville Power Administration (BPA) has funded a project to re-introduce chum salmon into Duncan Creek and to estimate contribution of different re-introduction strategies to the abundance of chum salmon in this creek and adjacent spawning areas (Hillson 2002 and 2003). As part of this project, different test groups of juvenile chum salmon are otolith marked with unique codes (Schroder et al. 1995; Volk et al. 1990, 1994 and 1999). To evaluate the contribution of these different strategies to the Duncan Creek population, spawning escapement will be measured at the fishway trap or through mark-recapture experiments. An otolith sampling program will identify the percentage of spawners returning from different re-introduction strategies. Since re-introduced chum salmon are likely to stray from Duncan Creek into adjacent areas (Salo 1991), accurate estimates of spawners in the mainstem Columbia River are needed, along with an otolith sampling program in these areas to assess the contribution of Duncan Creek spawners to Lower Gorge and Washougal chum salmon stocks.

Although chum salmon have been observed spawning in the mainstem Columbia River below Bonneville Dam for many years (Fulton 1970), there has been no effort to document the size of this spawning group until recent years (van der Naald et al. 2000). Area-Under-the-Curve (AUC) is the method used by Pacific States Marine Fisheries Commission (PSMFC) and Oregon Department of Fish and Wildlife (ODFW) to estimate mainstem Columbia River chum escapement (Keller 2002, van der Naald et al. 2002, and van der Naald et al. 2003). Although, they have also used the mark-recapture of carcasses and peak counts to estimate populations for the Ives Island group (van der Naald et al. 2000 and van der Naald et al. 2001). The Washington Department of Fish and Wildlife (WDFW) has expressed concern about the observer efficiency and residence time assumptions needed to develop accurate and precise AUC or peak count expansion population estimates for mainstem Columbia River spawning sites. Hilborn et al. (1999) and Parken et al. (2003) discuss these concerns in more detail. This paper summarizes efforts by WDFW, PSMFC, and ODFW to estimate chum salmon spawning in the mainstem Columbia River using mark-recapture methods in 2002 and compares these estimates with estimates obtained from previously used methods.

Study Site

A mark-recapture study to estimate mainstem Columbia River chum salmon escapements at the I-205, Multnomah, and Ives Island areas was conducted in 2002 (Table 1 and Figure 1). The lowest spawning site is located east of Vancouver, WA upstream of the I-205 Bridge. The Ives Island site, which is uppermost, is located just downstream of Bonneville Dam. The distance between sites is approximately 33 miles. The width of the Columbia River in this area ranges from approximately 0.2 to 1.7 miles; the depth of the shipping channel is 42 feet, although depths can exceed 100 feet in some areas. River stage was measured on left bank 0.9 mile downstream from the Bonneville Dam powerhouse, approximately 50 feet upstream from Tanner Creek (Rm144.5). The exact location is Lat 45° 38'00", long 121° 57'33", in sec.21, T.2 N., R.7 E., Multnomah County, Hydrologic Unit 17080001. River stage ranged from 16.6 to 11.5 feet , averaging 11.8 feet, during the study. The hourly Columbia River discharge measured at Bonneville Dam ranged from 192.0 kcfs to 80.1 kcfs, and averaged 123.2 kcfs during the study period. Discharge at Bonneville Dam was variable and generally increased during nighttime hours for power generation (Figure 2).

Table 1. Location of Chum Salmon spawning sites and landmarks on the Columbia River.

Location/Name	Latitude/Longitude (Approximate Location)	Side of River (Washington/Oregon)	River Km
Bonneville Dam	45 38.4272 / 121 56.7265		235.1
Tanner Creek	45 37.9518 / 121 57.5840	Oregon	232.5
Top of Ives Island	45 37.5756 / 121 59.1282	Washington	230.9
Hamilton Slough	45 37.6129 / 121 59.8093	Washington	228.2
Hamilton Bay/Pocket	45 37.5178 / 121 59.8093	Washington	228.2
Channel between Ives & Pierce Is.	45 37.2613 / 121 59.8799	Washington	228.2
McCord Creek	45 36.9679 / 121 59.9092	Oregon	230.7
Woodward Creek	45 37.1705 / 122 1.0775	Washington	227.5
Duncan Creek	45 36.9019 / 122 2.3099	Washington	226.4
Horsetail & Oneonta creeks	45 35.5331 / 122 4.4935	Oregon	222.2
Multnomah Creek	45 34.7895 / 122 6.8576	Oregon	218.8
Washougal River	45 34.7460 / 122 23.9453	Washington	193.9
River Shore area	45 35.3668 / 122 30.8256	Washington	182.1
Woods' Landing	45 35.7059 / 122 32.1345	Washington	181.9
Interstate Hwy 205 Bridge	45 35.7830 / 122 32.9136		181.8
Willamette River	45 39.1716 / 122 45.8228	Oregon	163.3

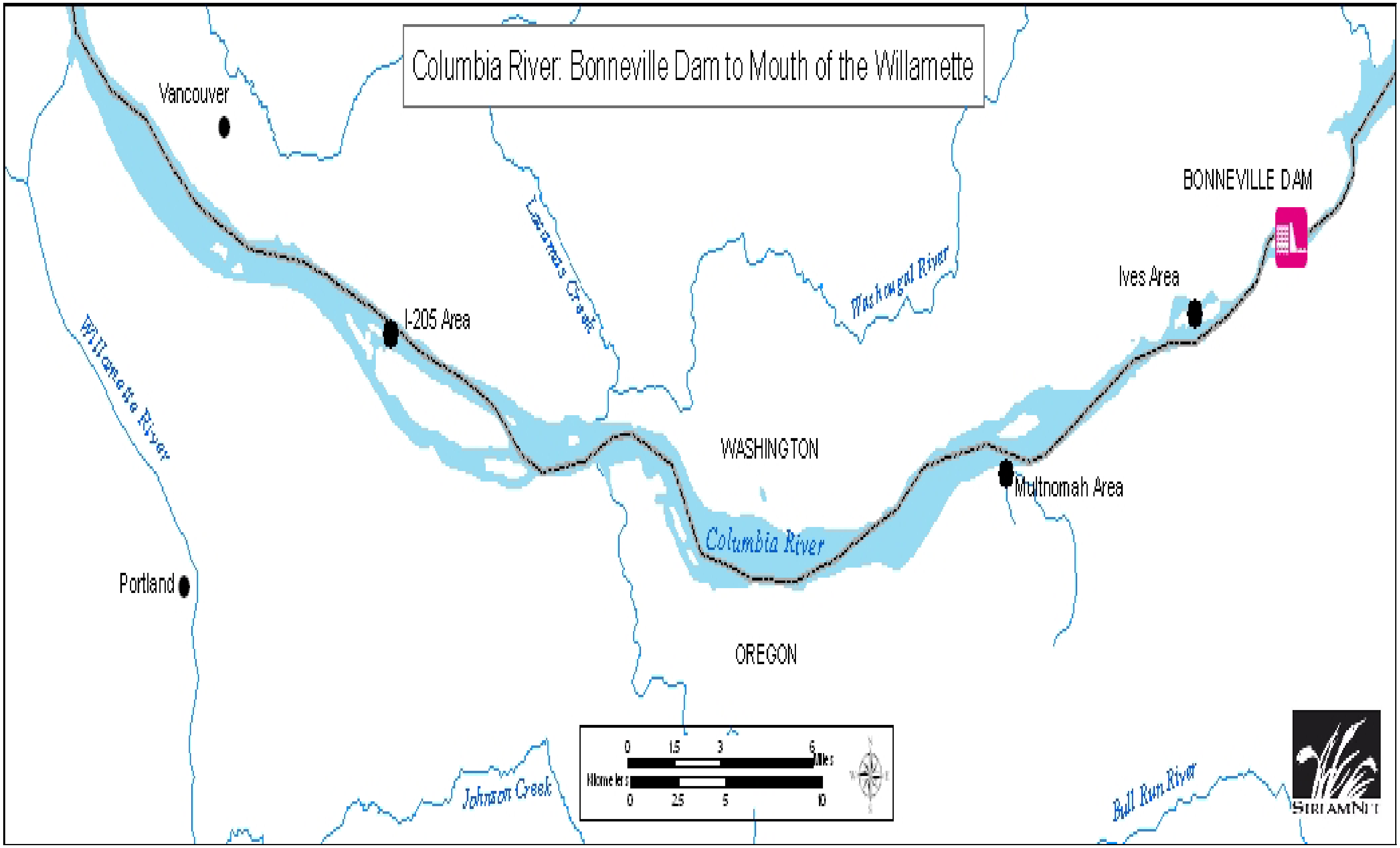

Figure 1. Columbia River from Bonneville Dam downstream to its confluence with the Willamette River showing the three main sampling areas for chum salmon in 2002.

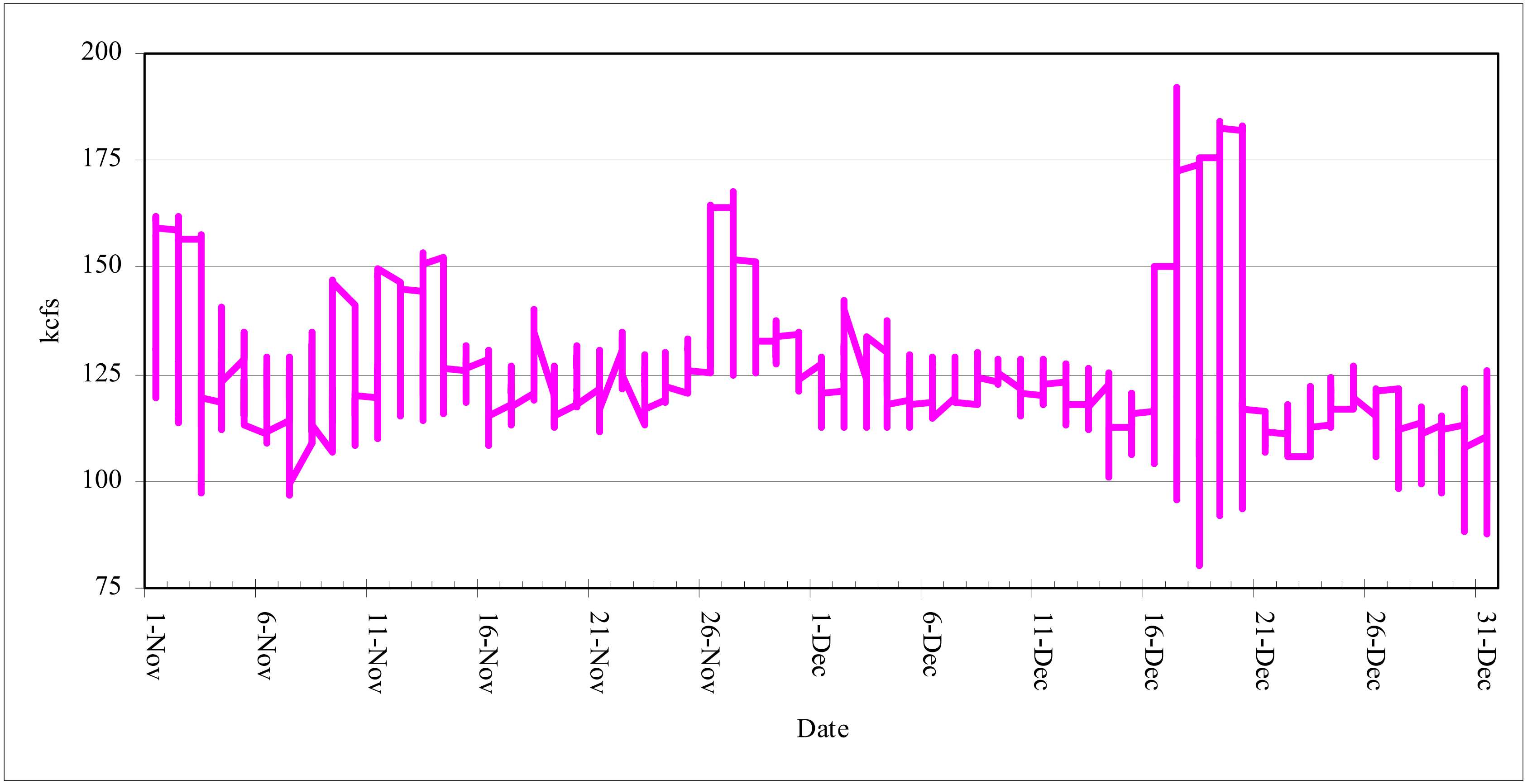

Figure 2. Hourly discharge at Bonneville Dam during the 2002 chum salmon spawning period.

Adults were collected from known shallow staging and spawning areas. Chum salmon in I-205 and Multnomah areas of the mainstem Columbia River are generally found spawning on gravel beaches associated with a groundwater source. At Woods' Landing, they use seeps that originate on the beach. These spawning areas are tidal and flow dependent (Figure 3). At the Rivershore and Multnomah areas, groundwater is provided by creeks as they percolate through broad alluvial gravel deposits. Chum salmon spawning in these areas use gravel from the river's edge, a depth of 4 inches, to an undetermined depth farther out in the river. Chum salmon spawning near Ives Island use gravel found in the sloughs, in the channels between islands, and adjacent to the islands and shore (Figure 4). Areas of highest use include the channel/slough (section 1), a bay/pocket that forms next to the Hamilton/Ives slough (section 2) the break between Ives and Pierce Islands (section 3), and near Woodward Creek (section 4) (van der Naald et al. 2003). The size and location of these spawning areas around the islands are highly variable and dependent on Bonneville Dam discharge and river elevation. The slough is thought to be primarily used by actively spawning adults, and the pocket is used by both spawning and staging adults.

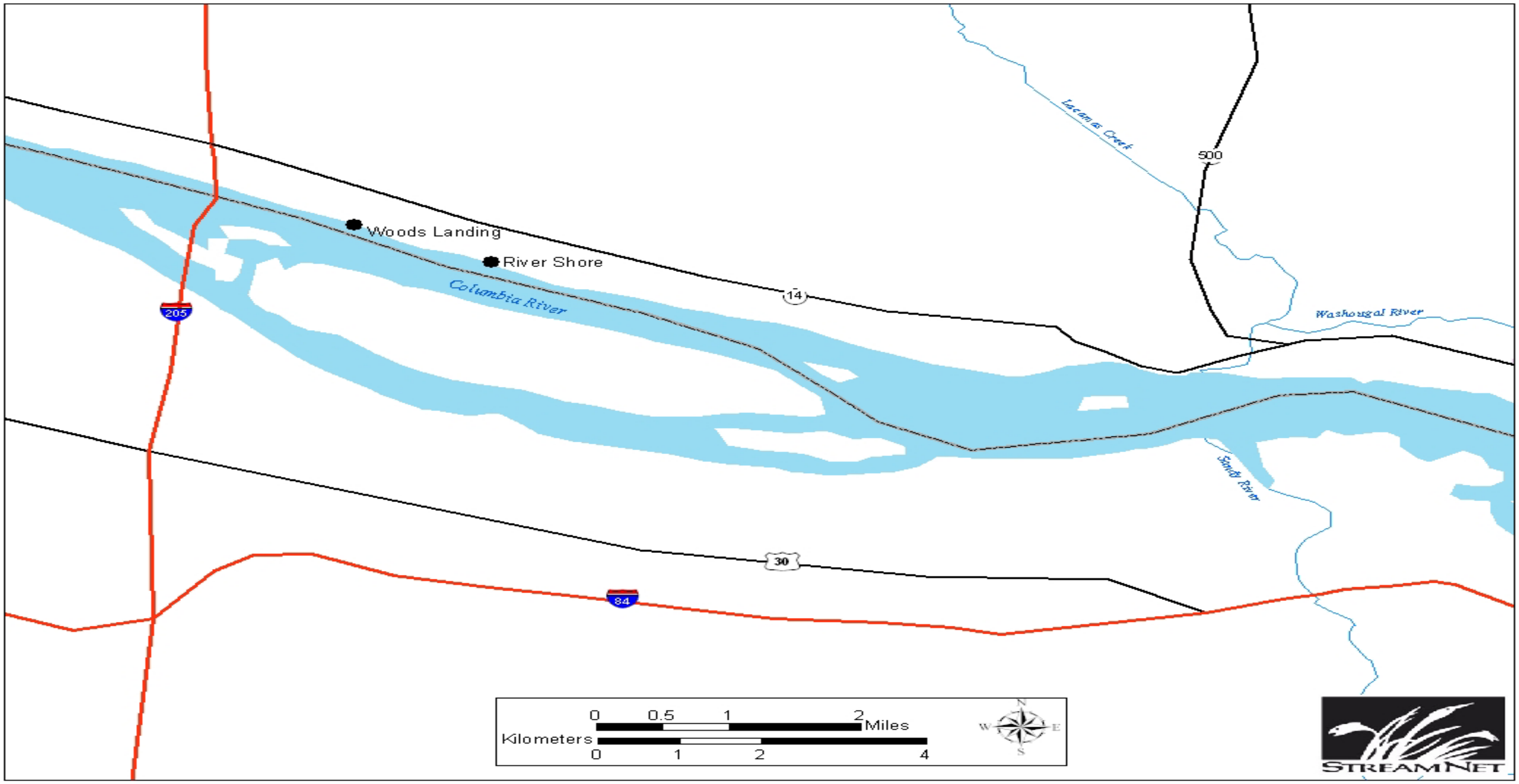

Figure 3. Map of chum salmon spawning sites upstream of the I-205 Bridge near Vancouer, WA.

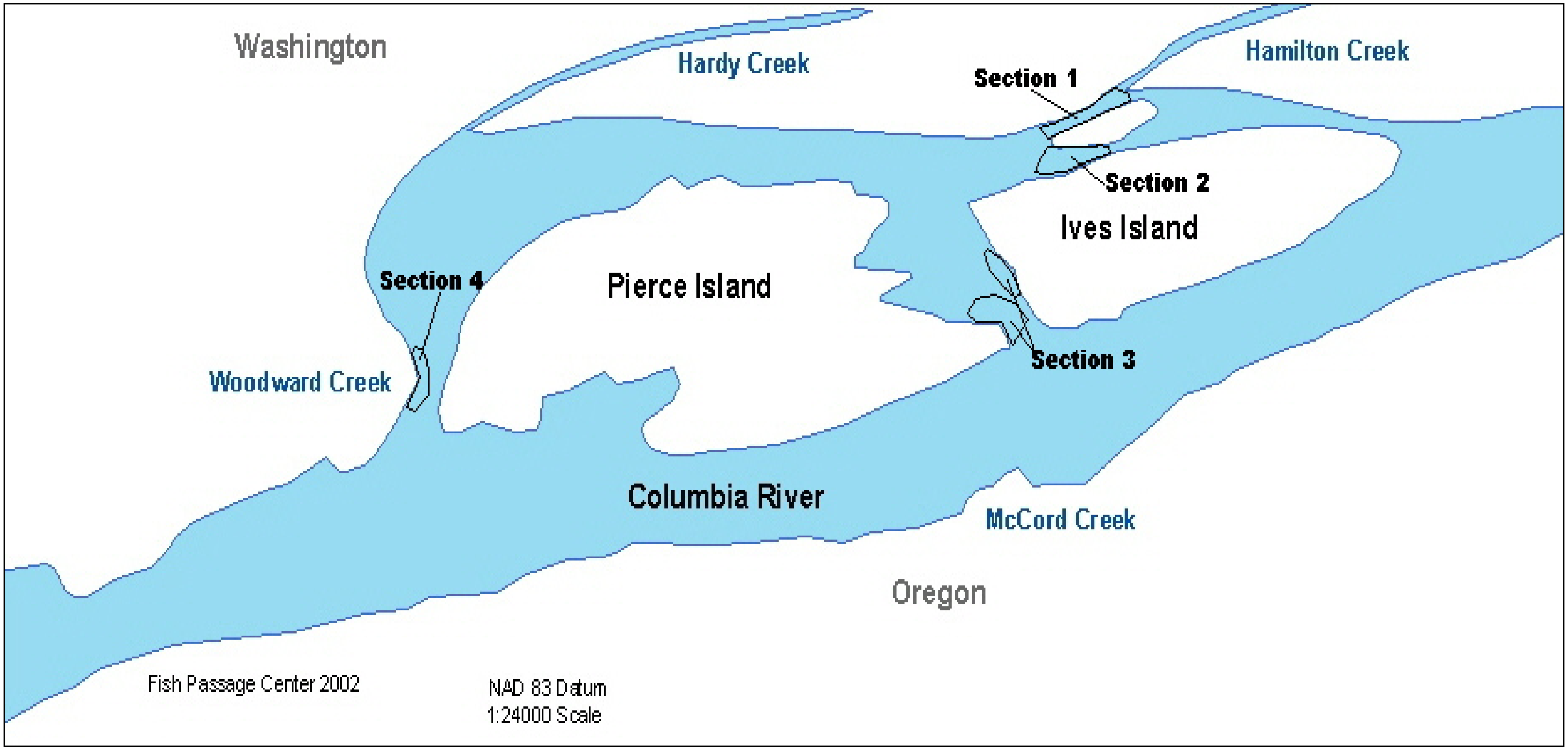

Figure 4. Map of chum salmon spawning sites near Ives Island downstream of Bonneville Dam near Cascade Locks, OR.

Methods

Field Sampling

From early November to late December, all three mainstem spawning locations were scheduled to be sampled weekly. A week of sampling was occasionally missed when high winds made boat operation and sampling in the Columbia River hazardous, or if the net sustained damage on the initial set and field repair was not possible. Sampling dates are found in Table 2. Adults were captured as they staged in shallow water for spawning and during spawning. Throughout the spawning season each location was tangle-netted using a 200 foot x 12 foot x 2 inch floating monofilament tangle net, which effectively fishes areas less than 10 feet in depth. These nets tangle adult salmon by their maxillary bones and teeth, not by the opercula as would happen in conventional gillnetting, allowing a very high rate of survival. Tangle nets are often the gear of choice when conducting salmon and trout mark-recapture studies (Schwarz et al. 1993 and Parker et al. 2001)

Table 2. Sampling dates for chum salmon in the mainstem Columbia River during 2002.

	Woods' / Rivershore Area (I-205)	Multnomah Creek Area	Hamilton/Ives/Pierce Island Area
Week (Dates)	Date(s) Sampled	Date(s) Sampled	Date(s) Sampled
1 (Nov. 3 - 10)			11/6
2 (Nov. 11 - 17)	11/14		11/13
3 (Nov. 18 - 24)	11/19	11/18	11/18 and 11/20
4 (Nov. 25 - Dec. 1)	11/27	11/25	11/25 and 11/26
5 (Dec. 2 – 8)	12/3	12/2	12/2 and 12/5
6 (Dec. 9 – 15)	12/13	12/11	12/9
7 (Dec. 16 – 22)	12/17 and 12/20	12/18	12/16
8 (Dec. 23 – 29)	12/24	12/23	

The Ives Island group was collected primarily from a pocket on Hamilton Slough (section 2), and it took approximately 20-30 minutes to capture the fish (Figure 4). The entire area was seined using two tangle nets joined to effectively create a block net that was eventually pulled to shore. Setting the net at the I-205 and Multnomah sites took 5-10 minutes. At these locations, river depth restricted the effective seining area and water velocity ensured the net was set close to shore. The net was used in the same manner as a beach seine. One end of the net was held onshore and the remainder played out of a boat as it pulled away from shore. The net was then pulled into the river parallel to the shoreline as far as current and net depth allowed. When this point was reached, both the boat and person onshore holding the net began to move downstream. At the end of the set, the person onshore would stop and the boat would swing the downstream end of the net to shore. Once both ends were on shore the net would be slowly brought in. Because some fish tangled in the mesh, fish were removed from the tangle net and placed in the holding seine (100 foot x 8 foot x 1 inch mesh, tied with 0.125" diameter twine). This process continued (bring in five to ten feet of the tangle net on both ends, and remove fish as they became available) until all fish were removed. The time to remove fish from the seine varied in direct proportion to catch and took over an hour when over 200 or more adults were seined at once. It took approximately 1 minute per fish to check for marks and collect biological data. All fish were released after marking.

Adult salmon were tagged with two individually numbered Floy anchor T-bar tags (Floy Tag & Manufacturing, Inc., Seattle WA.), one on each side of the dorsal fin (Waldman et al. 1990). A small hole in the opercle, made with a paper punch, served as a secondary mark to assess tag loss. The length, sex, degree of sexual maturity, condition, date, and location of tagged fish were recorded. Three different colors of Floy tags were used to uniquely identify the location of capture for recoveries during live counts. The tag color, number/numbers, absence of tags, absence/presence of opercle punch, and sex of each recaptured fish was recorded. Resource (time) constraints prevented tagging all captured chum salmon. However, all captured fish were examined for tags and enumerated by sex. A total of 8 and 12 adult chum salmon were Floy and radio tagged near the Ives Island area on November 6 and 13, respectively. In the Multnomah Area, another ten were Floy and radio tagged on November 13, followed by 20 in the I-205 area (ten at Woods' Landing and ten at Rivershore) on December 3. Recovery rates from seining for radio tagged fish were 4/50 and recovery rates for Floy tagged fish were 193/1142. While the power for the test was low, the test was not significant at $\alpha = 0.05$ (χ^2 with Yates correction factor = 2.43, 1df, p = 0.1191). If multiple recaptures occurred within a day, they were treated as a single recapture and carcass recoveries were recorded as losses-on-capture.

Another crew from PSMFC and ODFW also sampled when weather and water conditions permitted, to recover carcasses and make visual counts of live fish for an AUC estimate. These surveys generally occurred twice per week near Ives Island, and every week or two at the other sites. Sample periods were defined as weeks. We standardized weeks for all analysis, November 1 was assigned a value of 1.0. For each additional week the value increased by 1.0 and continued to increase until the end of sampling. For example, sampling in Multnomah area occurred on Nov 18, Nov 25, Dec 2, Dec 11, Dec 18, and Dec 23, and these would correspond to sample periods 3.4, 4.4, 5.4, 7.1, 8.1, and 8.8, respectively.

Statistical Analysis

The majority of mark-recapture studies to estimate salmon escapement have used the Petersen estimator. Parker (1968) estimated pink salmon escapement in the central British Columbia's Bella Coola River, from carcass mark-recapture data using the Jolly-Seber (JS) model. Stauffer (1970) used a similar study design to estimate chinook salmon escapement in Washington's Green River. McIssac (1977) developed salmon escapement estimates from salmon carcass mark-recapture data using a modified JS model developed by G. Paulik (University of Washington) and prepared by D.Worlund (NMFS) based on capture-recapture data (Jolly 1965 and Seber 1965). In carcass tagging all tagged carcasses that are recovered are marked by removing the tail, and treated as loss on capture. Sykes and Botsford (1986) compared the counts at the Bogus Creek weir in California to population estimates obtained from carcass tagging using the JS model and found for this basin population estimates were robust, accurate, and precise. Use of the JS model is not limited to carcass mark-recapture studies. Schwarz et al. (1993) used mark-recapture data collected from tangle nets, electroshocking, and carcass recoveries in the Chase River on Vancouver Island to develop escapement coho escapement estimates. Jones and McPherson (1997) used mark-recapture data from salmon captured with nets to estimate coho escapement into Steep Creek in southeast Alaska. Seber (1982) and Pollock et al. (1990) provide details of study design, assumptions, and analysis of mark-recapture experiments using the JS model. The notation and basic equations used in this paper are from Schwarz et al. (1993) and are found in Table 3.

Table 3. Notation used for Jolly Seber Estimates from Schwarz and Arnason (1996).

Statistics

ni	number of animals captured at sample time i, i=1…,k (ni = mi + ui).
mi	number of animals captured at sample time i that were previously marked.
ui	number of animals captured at sample time i that were unmarked.
li	number of animals lost on capture at time i.
Ri	number of animals that are released after the ith sample. Ri need not equal ni if losses on capture or injections of new animals occur at sample time i.
ri	number of Ri animals released at sample time i that are recaptured at one or more future sample times
zi	number of animals captured before time i, not captured at time i, and captured after time i.

Fundamental Parameters

k	number of sample times
pi	probability of capture at sample time i, i=1…,k.
Φi	probability of an animal surviving between sample time i and sample time i+1 given it was alive at sample time i, i=1, …,k-1
Bi	number of animals that enter after sample time i and survive to sample time i+1, i=0, …,k-1. The Bi are referred to as the net births. B0 is defined as the number of animals alive just prior to the first sample.
N	Total number of animals that enter the system and survive until the next sample Sample time. (N = B0 + B1 + … + Bk-1).
βi	fraction of the total net births that enter the system between sample times i and i+1, i=0, …, k-1. We refer to these as the entry probabilities. βi=Bi/N
vi	probability that an animal is captured at time i will not be released,i=1,…,k.

Functions of parameters

λi	probability that an animal seen again after sample time i, I=1,…,k. λi = Φi pi +1 + Φi (1- pi +1) λi +1, i=1,…,k-1; λk = 0;
τI	conditional probability that an animal is seen at sample time i given that it was seen at or after sample time i, i=1,…k. (τi = pi/(pi + (1-p1) λi), i=1,…k.)
ψI	probability that an animal enters the population and is not seen before time 1, i=1,…,k-1. (ψ1 = β0, ψi+1= ψI(1-p1) Φi + βI)
Ni	population size at time i. (N1 = B0, Ni+1 = (Ni-ni+Ri) Φi + Bi)
Ui	number of unmarked animals in the population at time i. U1 = 0; Ui+1 = Ui (1-pi) Φi + Bi
B*i	gross number of animals that enter between sampling occasion i and i+1. These include animals that enter and die before the next sampling occasion.

Assumptions to recruitment between sampling occasions are needed to estimate annual salmon escapement from the JS model. Stauffer (1970), McIssac (1977), and Sykes and Botsford (1986) assume that recruitment took place at the mid point and the adjustment factor for this assumption is $(1/\text{sqrt}(\phi_i))$, where ϕ_i = the probability that an animal alive at sampling occasion i will be alive at sampling occasion (i+1). Crosbie and Manly (1985) and Schwarz et al. (1993) assume uniform recruitment with an adjustment factor of $(\log \phi_i / (\phi_i -1))$. Schwarz et al. (1993) conducted a sensitivity analysis to these and other distributions of adult recruitment. Adjustment factors are similar when survival is high because most fish survive to the next sampling occasion. However, when survival is low the adjustment factors varied considerably. These authors noted the actual distribution of recruitment is unknown, and care should be taken in choosing a recruitment adjustment factor. In their analysis the performance of the mid-point and uniform adjustment factors was similar and we used the uniform recruitment distribution in our analysis.

All recruitment parameters at the beginning and end of the sampling periods cannot be estimated without further assumptions. A well-designed mark-recapture study should commence before a significant number of fish enter the stream or spawning area, and extend until recruitment is completed. Therefore, if studies extend to the end of recruitment, Schwarz et al. (1993) suggest that net births (B_{s-1}) should approach zero, with little effect on the population estimate. At the start of the study, the JS model is not able to directly estimate births (B_0 and B_1) because the probability of capture is not identifiable without making further assumptions. However, it may be reasonable to assume that for the probability of capture p(1) = 1, (p1) = (p2), or pi = constant. Any of these assumption makes it possible to estimate (B_0 and B_1). These assumptions will be discussed further in model selection.

Following the notation from Schwarz et al. (1993), escapement is the total number of fish emigrating between the first and last sampling occasions, called gross births (B^*_i), plus the number of fish that entered before the first sampling occasion (B^*_0), plus the fish entering after the last sampling occasion (B^*_s) and is estimated as:

$$E = B^*0\ \phi 1\ (\log \phi i /(\phi i -1)) + B^*i\ \ldots B^*s - 2 + B^*\ s - 1 \qquad (1)$$

Where E = escapement, B^*_i = gross births, and ϕ_i = the probability that an animal alive at sampling occasion i will be alive at sampling occasion (i+1). Escapement is calculated as the number present in the first sampling event plus new individuals immigrating prior to each sampling event i = 2, … , s:

$$E = N_2 (\log \phi_1 /(\phi_1 -1)) + B_2 (\log \phi_2 /(\phi_2 -1)) + \ldots + B_{s-1} (\log \phi_{s-1} /(\phi_{s-1} -1)) \qquad (2)$$

where N_i = the number of animals alive in the system at sampling occasion i, (abundance), B_i = the number of animals that enter the river after sampling occasion i and are still alive at i+1, (births). Asymptotic large sample variances were derived from the net recruitment using the Delta method (Schwarz and Arnason 1996).

Schwarz et al. (1993) evaluated the performance of less biased estimators, censored maximum likelihood estimators (MLEs) and constrained MLEs. They demonstrated through simulations that constrained solutions, $0 \leq \phi_i \leq 1$ and $Bi \geq 0$, provide realistic estimates of parameters and their variance. Schwarz and Arnason (1996) proposed generalizations to the JS model that led to simplification of the likelihoods and allowed for constraints to be applied to the parameters. In this paper we followed the methodology Schwarz and Arnason (1996) to develop standard parameter estimates, standard error (SE), and derived estimates including salmon escapement and its SE. These estimates and SE have been programmed as part of POPAN, an integrated computer system for the analysis of capture-recapture data (Arnason et al. 1998). This analysis was run at an online version of POPAN-6 available at http://www.stat.sfu.ca/~cschwarz/Carlan.online.

The assumptions of the JS Model are (Seber 1982):

1. Every animal in the population whether tagged or untagged, has the same probability of being caught in the i^{th} sample (p_i) given that it is alive and in the population when the sample is taken;

2. Every tagged animal has the same probability of surviving (ϕ_i) from the i^{th} to the $(i+1)^{th}$ sample and of being in the population at the time of the $(i+1)^{th}$ sample, given that it is alive and in the population immediately after the i^{th} release;

3. Every animal caught in the i^{th} sample has the same probability of being tagged and returned to the population;

4. Tagged animals do not lose their marks and all marks are recognized on recovery; and

5. All samples are instantaneous, i.e., sampling time is negligible and each release is made immediately after the sample.

Model Selection

To obtain unbiased population estimates from the model, the five JS assumptions must be met. A number of experiments and statistical tests were used to evaluate if the above assumptions were violated, the extent of the violation, and where possible to provide adjustments to the data and/or analysis to obtain unbiased estimates. Handling mortality (assumption 3) was estimated during broodstock collection where captured fish were transported to the Washougal Hatchery and Duncan Creek spawning channel. Survival of chum salmon released in both locations was closely monitored. Tag loss (assumption 4) was assessed through the application of a permanent secondary mark and examination of captured fish for primary and secondary marks.

To test for a possible violation of other assumptions the goodness-of-fit (GOF) tests developed by Pollock et al. (1985) and test for homogeneity of groups using the RELEASE program were used (Burnham et al. 1987). Biologists have found that the probability of recovering salmon is often influenced by age and/or size, and sex (Boydstun 1994, Zhou 2002, Hahn 2002, Schwarz and Arnason 1996). Seber (1982) recommends that homogeneity in length be tested by a comparison of those captured and not recovered to those captured and recovered using a Kolmogorov-Smirnov (K-S) test. TEST 1 in RELEASE was used to test for differences between sexes. The null hypothesis (Ho) for this test is that all parameters (pi and ϕi) have the same value across groups (male and females), while the alternative hypothesis (Ha) is that at least some of the values for pi and ϕi differ among males and females. TEST 1 is computed as a series of χ^2 contingency tables.

TEST 2 in RELEASE tests assumption (1), which is the basic assumption of "equal catchability" of marked animals. The null hypothesis (Ho) for this test is that the parameters pi and ϕi are specific to sampling occasions within each group, and the alternative hypothesis (Ha) is the model does not fit the data. This test is logically equivalent to fitting the model to the data, then computing the expected values of E(mij | Ri) given the fitted parameters and using a χ^2 test comparing the observed vs. the estimated expected (Cooch and White 2003). In general TEST 2 (often referred to as the recapture test) is sensitive to short-term capture effects or non-random temporary emigration.

TEST 3 in RELEASE is often referred to as the "survival test" and examines assumption 2, that all marked animals alive at (i) have the same probability of surviving to (i+1) (Cooch and White 2003). The null hypothesis (Ho) is the parameters pi and ϕi do not depend on capture histories of fish released on any release occasion and the alternative hypothesis (Ha) is that some of the parameters (pi and ϕi) are dependent on the capture histories of fish released on any occasion. The overall GOF test is a χ^2 test that is the results of TEST 2 plus TEST 3 in RELEASE.

The framework of Lebreton et al. (1992) was followed for model selection. A global model compatible with the biology of the species studied was selected, and its fit assessed. The GOF test from RELEASE was used to assess model fit and if the null hypothesis (Ho) fit the data, we proceeded to model selection. POPAN 6 used the model notation adopted by Lebreton et al. (1992). The initial global model we selected was full or unrestricted JS model, characterized by p_{g*t}, $\phi_{g*t,}$ and β_{g*t}, which implies that capture, survival, and entry probabilities vary over groups and time periods, denoted by g*t (Schwarz and Arnason 1996). In this model not all parameters are identifiable and constraints must be imposed on p_1 and p_s to produce an estimate of salmon escapement; these parameters are set equal to 1 in the full model. These same constraints must also be imposed when capture probabilities vary over time (p_t). Estimates of precision with the unrestricted model are usually poor because of the large number of parameters (Arnason et al. 1998).

The principle of parsimony leads to a model with as few parameters as possible that provides and adequate explanation of the data. A more parsimonious model was selected using AIC defined as:

$$AIC = -2 * -\ln L + 2 *np \qquad (3)$$

where –ln L = the negative log likelihood model fit to the data and np = the number of parameters in the model (Akaike 1973). Constant parameter models which may yield better estimates of precision, where some or all of the p_i and/or ϕ_i are assumed to be equal, were explored. For example, in POPAN 6 notation, ϕ_g implies that survival probabilities are constant across time within groups but vary between groups, while ϕ_{same} implies that survival probabilities are constant across groups and time. Constraints across time were evaluated, where (ϕ_t) implies that survival probabilities are the same for both groups within each time period but vary across time periods. Finally, population estimates were reported with their SE as obtained from POPAN 6.

Results

Sample Data

Prior to this data analysis limited information was available on the extent of movement between mainstem Columbia River chum salmon spawning locations. In this study, 174 live tagged fish were recovered from the same location in which they were tagged. However, a total of 12 (6.4%) live fish were recovered in different locations. Nine of these twelve were fish that moved within the I-205 site; all of these fish moved downstream from Rivershore to Woods' Landing (Figure 3). This movement supports our decision to treat the Woods' Landing and Rivershore areas as one group, called the I-205 group. Therefore, based on seining recoveries approximately 2% (3/174) of the population moved between mainstem spawning groups.

A total of 94 tagged carcasses were recovered. For the I-205 group, 6% (1/15) of the carcass recoveries were from outside the tagging area. For the Multnomah and Ives groups, 18% (2/11) and 23% (13/67) were recovered outside the tagging area. One chum salmon tagged at Multnomah was recovered near Ives Island and one in Hamilton Creek. Seven and six of the chum salmon tagged in the Ives area were recovered in Hamilton and Hardy Creeks, respectively. Carcass recoveries indicate more movement between sites than the live recaptures. Radio tagging indicated movements between Columbia River spawning sites (Robin Ehlke – PSMFC and Nancy Uusitalo –USFWS Pers. Comm.). This information suggests it may not be appropriate to use the Petersen estimate due to a violation of the closure assumption (Seber 1982). If tags from one location are recovered at another location, then a JS model is an appropriate method of estimating abundance in open populations (Pollock et al. 1990).

Recoveries (mi) and (ri) were low in this analysis. When no marked fish were recovered in a sample (mi = 0), the POPAN 6 MLE of abundance (Ni) and consequently births (Bi) are infinite and the program will not converge. When no males where recovered in a sampling period, recoveries were pooled with adjacent periods; the same procedure was followed for weeks in which no females were recovered. Hargrove and Borland (1995) found that pooling led to nearly unbiased estimates if survival was high (>50%) for each of the pooled intervals. However, our survival was lower (10%) and increased the potential for bias. At Multnomah at least one recovery of each sex was obtained during each sampling occasion. Therefore no pooling of sampling periods was required at this site. At I-205, no recoveries of tagged females occurred during sampling periods 2, 3, and 8 and these were pooled with adjacent periods to a total of 5 sampling occasions. At Ives Island, ten sampling occasions were pooled to seven. Even after pooling, recoveries often remained less than 5 per sex per sampling occasion.

The rule of thumb in mark-recapture experiments is that 5-10 marked animals be recovered per release to produce unbiased estimates (Schwarz and Taylor 1998). Chapman (1951) and Bailey (1951) recommend 7 recaptures and Seber (1982) recommends 10 recaptures per period for unbiased JS estimates. Practically, this is difficult to achieve during the initial and final sampling periods because few fish are present. Even if the sampling period estimate is biased during these initial and final weeks, it has little effect on the total population estimate because few fish are present at the beginning and end on a well-designed study. However, even during the middle sampling periods in this study often less than 5 tagged fish were recovered. Equal probabilities of recapture were tested between sexes by comparing the recovery rates using the χ^2 test statistic from TEST 1 in RELEASE. The results for TEST 1 were not significant at the α = 0.05 level.(χ^2=10.2493, (df=6), and P=0.1145 for the Multnomah group, χ^2=4.4196, (df=10), and P=0.9264 for the I-205 group, and χ^2=15.4093, (df=11), and P=0.1645 for the Ives Island group). Therefore, the data was analyzed by sex but we also analyzed by adults, where males and females were combined to increase recoveries during the sample period. In the following section we review the assumptions for the JS model and analysis to determine if the assumption was violated, the magnitude of the violation, and the correction to data or the bias in the estimate.

Assumptions

Assumption (1) – Equal Catchability: Every animal in the population whether tagged or untagged, has the same probability of being caught in the i^{th} sample (p_i) given that it is alive and in the population when the sample is taken.

Seber (1982) recommended that equal catchability for length be examined using a K-S test. Lengths of fish tagged and recovered were compared with lengths of fish that were tagged and not recovered. The results indicated the differences were not significant for females at all sites and for males at the Ives and 1-205 site (p values > 0.168) (Table 4 and Figure 5). The only significant difference occurred at the Multnomah site for males (p=0.024) and may be the result of a low number of recaptures (10). These data indicate that recapture probabilities did not vary by length. Schwarz and Arnason (1996), Boydstun (1994), Zhou (2002), and Hahn (2002) noted a difference in recovery rates for jacks and adults. Our lack of significance in this test may be attributed to the different age structure of chum salmon in the Columbia River compared to the chinook and coho salmon in these previous studies. Chinook and coho salmon populations have a significant proportion of male spawners that return as jacks but Marr (1943), Keller (2000), Bruce and Keller (2001), and Keller (2002) reported that Columbia River chum salmon mature at ages 3, 4, and 5 and do not produce age 2 salmon (jacks).

Table 4. Summary table for recapture bias in length using the Kolmogorov-Smirnov test.

		D Value	P Value	D Value	P Value	D Value	P Value
I-205	Male	0.1270	0.365	0.4081	0.040	0.1037	0.529
	Female	0.1764	0.429	NSD	NSD	0.1509	0.541
	Both	0.1380	0.110	0.2977	0.103	0.1084	0.252
Multnomah	Male	0.4608	0.024	NSD	NSD	0.4465	0.007
	Female	0.2617	0.168	NSD	NSD	0.1858	0.426
	Both	0.1259	0.756	NSD	NSD	0.0849	0.954
HIP area	Male	0.1873	0.225	0.1407	0.712	0.1281	0.393
	Female	0.1798	0.421	0.0948	0.991	0.1114	0.739
	Both	0.0768	0.905	0.0929	0.827	0.0617	0.896

- If P value < 0.05, there is a significant difference in recoveries by length.

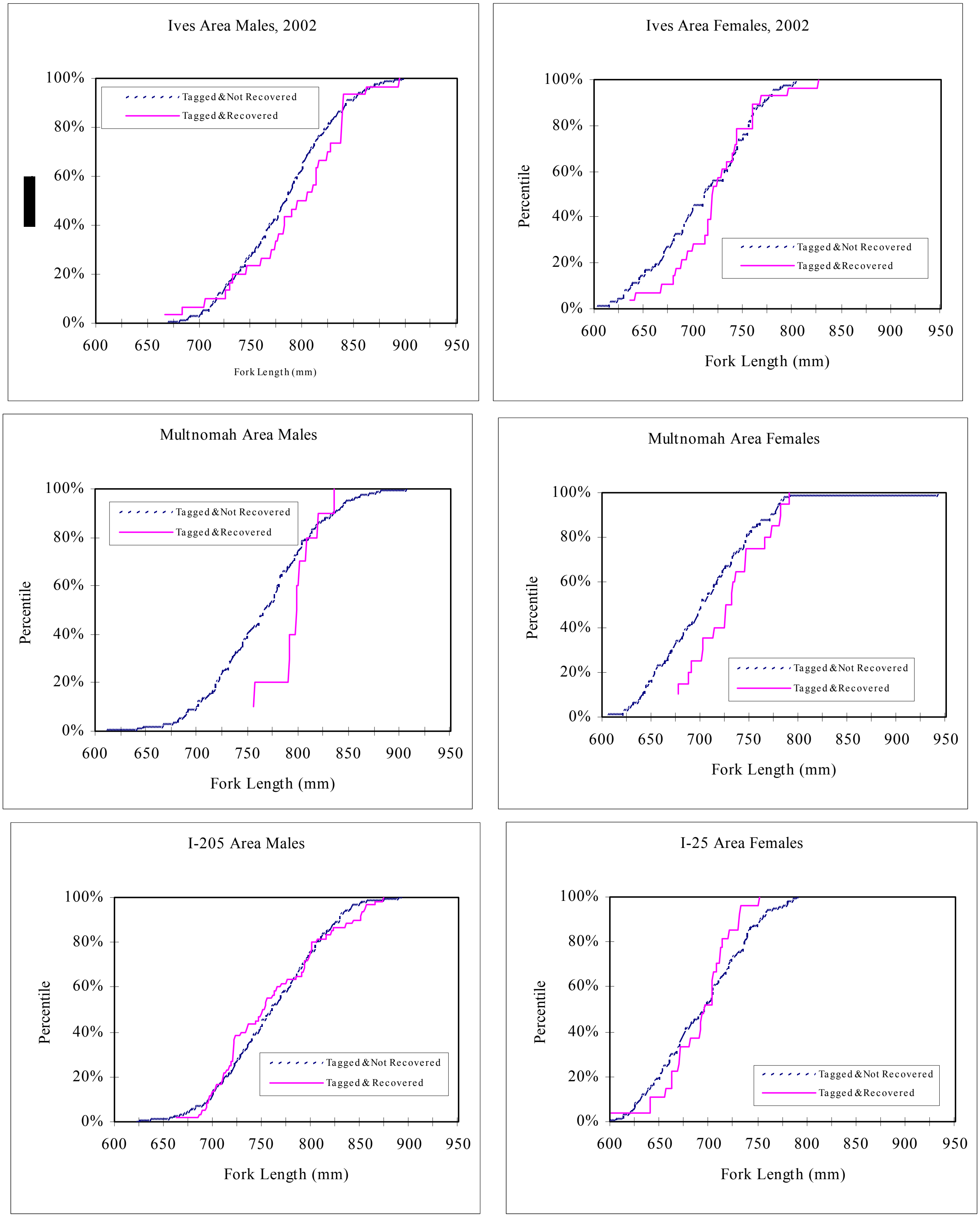

Figure 5. Cumulative length distribution of tagged and recaptured versus tagged and not recaptured used in Kolmogorov-Smirnov Test.

Equal catchability was examined using TEST 2 in RELEASE. Data for the Multnomah group was sparse (often ri =1) and TEST 2 produced no results. The data was also sparse for the other two sites but TEST 2 indicated that no significant differences were found at I-205 and Ives Island groups for males and females (Table 5).

Table 5. Results for TEST 2 "equal catchability" test from RELEASE for mainstem Columbia River chum salmon sites in 2002.

Group	$\chi 2$	df	P value
Ives Males	0.3028	3	0.9595
Ives Females	0.0000	2	1.0000
Ives M&F	0.3028	5	0.9976
I-205 Males	1.4582	2	0.4823
I-205 Females	0.0000	2	1.0000
I-205 M&F	1.4582	3	0.6919

Assumption(2) - Survival: Every tagged animal has the same probability of surviving (ϕ_i) from the i^{th} to the $(i+1)^{th}$ sample and of being in the population at the time of the $(i+1)^{th}$ sample, given that it is alive and in the population immediately after the i^{th} release.

Equal survival probabilities of marked animals were examined using TEST 3 in RELEASE. Unfortunately, too few recaptures of previously marked fish occurred to obtain results for TEST 3. Results of the GOF test, which is the sum of TEST 2 & 3, for the Multnomah group provided no results as the data were too sparse. For Ives and I-205 groups the GOF tests were not significant. P values for the Ives and I-205 groups were 0.9976 and 0.6919, respectively. There was insufficient data for TEST 3 so only the recapture test was used to assess GOF.

Assumption (3) - Handling Mortality : Every animal caught in the i^{th} sample has the same probability of being tagged and returned to the population.

Direct estimates of handling mortality from mark-recapture experiments are not possible. Research indicates that direct mortality from handling is likely to be observed within the first 24-48 hours (Muoneke and Childress 1994, and Wilkie et al. 1996). To assess the effect of handling mortality, we used the chum salmon captured and transported to Washougal Hatchery and Duncan Creek. A total of 171 broodstock were captured and transported to Washougal Hatchery. Fish were held a total of 1-2 days at this facility before spawning in 2002. A total of three pre-spawn mortalities yielded a 1.75% mortality rate for chum salmon collected for broodstock. This mortality rate is assumed to be higher than expected for salmon captured and returned to the river, since fish spawned at the hatchery received additional stress due to transport to the hatchery and being held in the adult holding pond prior to spawning.

Since chum salmon remaining in the natural environment have residence times longer than two days (Ames 1984, Rawding 2003, Perrin et al. 1982), it was necessary to assess the potential impact of handling on longer-term survival for the period of time a chum salmon remained alive in the spawning area. Average residence time for fish captured and released into Duncan Creek in 2002 was 6-7 days and 6 days for chum salmon spawning near Ives Island. Any female with high egg retention may have been died prematurely due to handling induced mortality. Egg retention rates greater than 10% (Steve Schroder pers. com.) or 500 eggs (Fukushima and Smoker 1997) may indicate a potential for handling induced mortality. A total of 21 females were released early and late in Duncan Creek. Eighteen of these females were recovered as carcasses and later sampled for egg retention. Egg retention ranged from 0% up to 9.3% or 281 eggs. Lister and Harvey (1969) compared the pre-spawning mortality of tagged and untagged chum salmon in Big Qualicum spawning channel from 1963-1966, and found no difference. Chum salmon research at Big Beef Creek, where adults were trapped, anesthetized, and tagged also experienced negligible pre-spawning mortality (Steve Schroder per comm.). Based on the short and long-term survival information, the mortality rates from capture and tagging were likely immeasurable and the handling induced mortality assumption was not substantially violated.

<u>Assumption (4) - Tag Loss: Tagged animals do not lose their marks and all marks are recognized on recovery.</u>

Tag loss and missing tags can bias mark-recapture experiments (Arnason and Mills 1981, Rajwani and Schwarz 1999, Lister and Harvey 1969). An experienced crew closely examined all fish and collected biological data including scales, tissue samples for DNA analysis, lengths (fork and mid-eye to hypural) sex, fin clips, tags, and marks. Due to the small number of fish handled, the extensive sampling, and the experience of the crew, it is unlikely that tags were overlooked.

Tag loss was assessed directly in this experiment. Captured chum salmon were Floy tagged with two uniquely numbered tags that were inserted at the base of the dorsal fin (Waldman et al. 1990). A permanent secondary mark, an opercle punch, was applied to all Floy tagged fish. The probability that an individual lost one or both tags was determined using recapture data. If the probability of losing a single tag is 22%, then the probability of losing both tags is 22%^2 or 5%, if tag loss is an independent event (Table 6). Similarly, the percentage of fish that lost both tags is calculated by dividing the opercle only fish by total number of tagged and opercle marked fish. Both methods indicate that about 6% of the tagged fish lost both tags. Observed complete tag loss, when fish lost both tags, ranged from 3% to 14% at these three sites.

Table 6. Chum salmon tag loss estimates by group.

Group	Recaptured Adults	Available Tags	Actual Tags	Tag loss (Percentage)	Probability of losing both tags	Percentage of fish that lost both tags
Multnomah	29	58	42	27%	8%	14%
I-205	85	170	131	23%	5%	6%
Ives Island	65	130	105	19%	4%	3%
Total	179	358	278	22%	5%	6%

Tag loss data and χ^2 test statistics for Columbia River chum salmon are found in Table 6. Complete tag loss for males ranged from 8% to 36% and averaged 14%. No seined females were observed to have lost both tags, although based on single tag loss we would have expected 2% of females to have lost both tags. Tag loss between sexes was estimated using a χ^2 test with Yates correction factor that compared opercle only recoveries to fish that retained at least one tag. P values for the Ives, Multnomah, and I-205 groups were 0.328, 0.016, and 0.344, respectively. Overall, complete tag loss for males was 14% and this result was significantly different than for females (0%) (χ^2 =7.4, df=1 p = 0.006). Lister and Harvey (1969) found that Petersen Disc tag loss was significantly higher for males as well and they attributed this loss to more aggressive behavior of male chum salmon on the spawning grounds.

Arnason and Mills (1981) conducted a theoretical analysis of tag loss in the full JS model and found that abundance (Ni) estimates were not biased but survival (ϕi) and births (Bi) were biased. Since escapement in each period (gross births - B*i) is a function of births and survival (B*i = B_i (log ϕ_i /(ϕ_i -1))), unaccounted tag loss will create positive bias in the escapement estimate. Schwarz et al. (2000) suggested that unread tags (opercle punch only) be assigned to the most likely group by distributing unread tags into their respective rows in proportion to total tags recovered in the period to obtain population estimates using a stratified Petersen model. A total of five, five, and two male recaptures had lost both tags from the Multnomah, I-205, and Ives groups, respectively. These fish were assigned to the most likely capture life history group. While this potentially allows for unbiased population estimates, the reported variances will be too small because the uncertainty associated with tag loss is not incorporated into the variance estimate.

Assumption(5) - Instantaneous Sampling: All samples are instantaneous, i.e., sampling time is negligible and each release is made immediately after the sample.

Sampling took place at each site from a three to six hour period per week. The sampling duration was not instantaneous, it is believed to be small enough that a serious violation of this assumption was not likely. Recapture data was sparse and recaptures did not always occur in every sampling occasion. When this occurred adjacent samples were pooled. For example if there were no recaptures in week 4, then weeks 3 and 4 would be pooled, and relabeled week 3.5 (Schwarz et al. 1993). On any given day seining may have occurred more than once at the same site. If multiple recaptures occurred during a day, they were counted as a single capture.

Population Estimates by Spawning Location

For each population group population estimates were reported by sex from the unrestricted model and a more appropriate model was selected based on AIC. Since TEST 1 indicated it was appropriate to combine sexes, the results of the unrestricted model were reported as adults (males and females combined). The final population estimate is selected based on AIC for adults.

Multnomah Group

For the Multnomah group, a total of 282 adult chum salmon were tagged. The peak day of seining occurred on December 2, when 139 adult salmon were captured. The minimum number of fish handled includes the number tagged throughout the season, plus the number of untagged fish released on the last day, since untagged fish released earlier in the season could have been recaptured. On the last day of tagging at this site all captured fish were tagged, making the season total 282 fish (Table 7). Summary statistics for this group are found in Table 8. Using the full JS model with males and females separately a total of 1,339 adults were estimated with a

SE of 117. Model selection using AIC indicated the model (g t g*t) was the best model and the population estimate and (SE) were 1,662 (349). Since recoveries were low (ri<2) and TEST 1 indicated no difference between sexes in probabilities of recapture, the population using the full model with one group of adult chum salmon was estimated. Using the full model, the chum salmon population estimate near Multnomah Falls was 1,282 adults (232). The final model selected using AIC was model (same t t) and yielded a population estimate of 1,267 adults with a 95% CI of 846 to 1,642, which is +/- 34% of the estimate.

Table 7. Seining summary statistics in 2002 by group for mainstem Columbia River chum salmon.

Group	Date	Peak Handled	New Tags	Last day untag release	Minimum handle
Ives	Dec 5	359	345	51	396
Multnomah	Dec 2	139	282	0	282
I-205	Dec 3	326	565	195	760

Table 8. Summary Statistics for the Multnomah Group of chum salmon.

	Week ti	Number of Captures ni	Number of Marks mi	Released after Marking Ri	Subsequently Recaptured Ri	Seen before i, not at i, and after i Zi
Male	1	47	0	34	4	0
	2	61	4	29	5	0
	3	93	4	43	3	1
	4.3	56	4	33	1	0
	5.3	43	1	43	1	0
	6	6	1	6	0	0
Female	1	19	0	19	10	0
	2	65	10	34	4	0
	3	46	4	16	2	0
	4.3	46	2	29	2	0
	5.3	25	2	24	2	0
	6	11	2	11	0	0
Adults	1	66	0	53	14	0
	2	126	14	63	9	0
	3	139	8	59	5	1
	4.3	102	6	62	3	0
	5.3	68	3	67	3	0
	6	17	3	17	0	0

I-205 Group

On December 3, a total of 326 adult chum salmon were seined from the Wood's Landing and Rivershore site. Over the course of the season, 565 salmon were tagged and the minimum number of adult salmon at this site, based on the total tagged fish and unmarked captures on the last day, is 760 fish (Table 7). Summary statistics for this group are found in Table 9. The full model with two groups (males and females) yielded a population estimate of 2,804 with an estimated SE of 330. Model selection using AIC indicated the model (same t g*t) was most appropriate. The population estimate using this model was 3,468 with a SE of 343. As with the Multnomah group, TEST 1 indicated no difference between sexes in probabilities of recapture and as the data were sparse we combined sexes for final model selection. The population estimate and SE from the full model were 2,850 and 390, respectively. Final model selection based on AIC indicated the model (same t t) was most appropriate. The final population estimate with this model was 3,468 with a SE of 180. The precision of the 95% CI was +/- 10% of the point estimate, and ranged from 3,116 to 3,820 fish.

Table 9. Summary statistics for the I-205 group of chum salmon

	Week ti	Number of Captures ni	Number of Marks mi	Released after Marking Ri	Subsequently Recaptured ri	Seen before i, not at i, and after i Zi
Male	1	74	0	61	10	0
	3	232	10	136	5	0
	4.4	112	4	102	21	1
	5	179	17	125	32	5
	5.4	236	37	44	0	0
Female	1	17	0	14	2	0
	3	105	2	54	1	0
	4.4	58	1	14	11	0
	5	66	9	59	13	2
	5.4	86	15	17	0	0
Adults	1	91	0	75	12	0
	3	337	12	190	6	0
	4.4	170	5	150	32	1
	5	245	26	184	45	7
	5.4	322	52	61	0	0

Ives Island Group

At Ives Island we sampled the largest two spawning sites but due to limited resources we did not sample the two smaller sites. The peak catch occurred on December 5, when 359 adult salmon were captured. Based on seining data the minimum number of chum salmon at this site was 396 fish (Table 7). The population estimate was 3,182 with a SE of 382 using the full model with both sexes. Summary statistics for this group are found in Table 10. Model selection using AIC led to the choice of the model (g*t g t) with a population estimate of 3,169 and SE of 372. Since data was sparse and TEST 1 indicated that sexes could be combined because there was no difference in probabilities of recapture by sex, we used one group (adults) to develop final estimates. The full model yielded a population estimate of 3,243 with a SE of 283. The final model selected based on AIC was model (t same t) and yielded a population estimate of 3,179 with a SE of 150. The 95% CI was 2,886 to 3,472, which is +/-10% of the point estimate.

Table 10. Summary statistics for the Ives Island group of chum salmon.

	Week ti	Number of Captures ni	Number of Marks mi	Released after Marking Ri	Subsequently Recaptured ri	Seen before i, not at i, and after i Zi
Male	1	42	0	42	6	0
	2	25	6	25	5	0
	2.7	65	2	33	13	3
	2.9	74	13	23	1	3
	3.7	98	2	19	3	2
	4.1	212	4	54	7	1
	5.1	248	8	68	0	0
Female	1	21	0	21	5	0
	2	16	5	15	3	0
	2.7	44	3	12	8	0
	2.9	36	5	15	2	3
	3.7	76	4	17	6	1
	4.1	88	3	19	8	4
	5.1	169	12	49	0	0
Adults	1	63	0	63	11	0
	2	41	11	40	8	0
	2.7	109	5	45	21	3
	2.9	110	18	38	3	6
	3.7	174	6	36	9	3
	4.1	300	7	73	15	5
	5.1	417	20	117	0	0

Discussion

JS Population Estimates from Seining Data

Model selection and ultimately population estimates must be based on biological and sampling information, and standard statistical considerations (Lebreton et al.1992). In examination of the seining JS estimates, there were differences in the observed and expected residence time and sex ratios. Koski (1975) defined the average residence time, from stream entry until death for female fall chum salmon in Big Beef Creek as 11.2 days. Lister and Harvey (1969) reported the average residence time for female chum salmon was ten days in the Big Qualicum spawning channel from 1963-65. Lister and Harvey (1969) also reported that the average time chum salmon spend from the start of spawning to death was 7 days. Lister et al. (1980) reported that in BC spawning channels chum spent 6 days spawning. The average life of chum salmon placed in the Duncan Creek spawning channel in 2002 was 6.7 days, with a 95% CI from 5.4 to 7.9 days (Figure 6). Assuming a normal distribution and errors, the residence time is 6.1 and the 95% CI estimated from likelihood profile is 5.8 to 6.5. (Figure 6). The residence time for the Ives Island Group was 6.1 days when the AUC estimate was calibrated with the carcass tagging data. Figure 8 is an estimate of the residence time for the Ives Island group and uncertainty assuming normal distribution and errors. Therefore, the expected residence time should be ~6 days. Manske and Schwarz (2000) demonstrated how mark-recapture data can be used to estimate aggregate fish days, residence time, and AUC escapement and incorporated these into POPAN 6. The average JS model stream residence time estimate from POPAN 6 for adults from all sites was 3 to 4 days. Our POPAN 6 estimates are about ½ to 2/3 of the expected value.

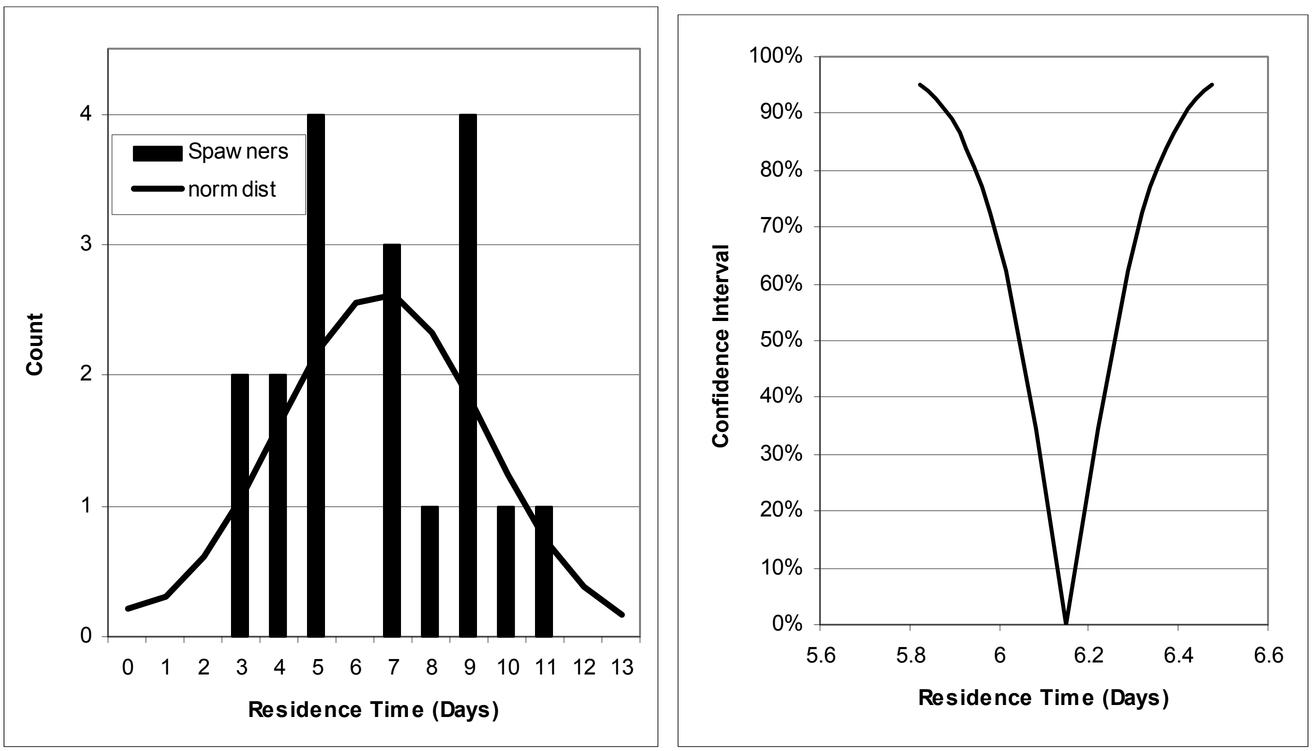

Figure 6. Plot of residence time for chum salmon released into Duncan Creek (left) and Likelihood Profile for residence time for chum salmon in Duncan Creek assuming a normal distribution and normal error structure

Fish released into Duncan Creek were selected to be in good condition and probably represented new arrivals in good condition. If the average residence time is 6 days, then tagged spawning fish represent those about ready to die and those that just began spawning. On average these deaths will take place at the mid-point or three days. Since the sampling frequency was ~7 days there was a low probability of recovering fish except to recover tagged fish that migrated to the spawning area on the day of tagging. Therefore, if tagged fish were recovered on average the residence should be close to the midpoint between sampling ~ 3.5 days. A second explanation is that chum salmon may only spend about 3.5 days at a site because there is significant movement between sites, as was evidenced by the Floy tag recoveries from live fish and carcasses at all sites (Table 11).

Table 11. Floy tagged chum salmon from carcass recoveries

Tagging Location	# Tagged	Recovered @ Ives	Recovered @ Mult.	Recovered @ I-205	Recovered @ Ham. Crk	Recovered @ Hardy Crk	Recovered @ Duncan Crk
Ives	345	54			7	6	
Multnomah	282	1	9		1		
I-205	565	1		15			

The second unexpected result is that sex ratios are skewed toward males. The population estimates based on the JS model using seining data indicate sex ratios of 2:1 or 3:1 in favor of males. This is in sharp contrast to sex ratios for other Columbia River chum spawning ground estimates, which averaged 1.4:1 for Hamilton Creek, Hardy Creek, and Grays River tributaries in 2002 (Ehlke and Keller 2003), which is closer to the long-term sex ratio for this species (1:1) reported by Salo (1991). Lister and Harvey (1969), Lister et al. (1980), and data collected on this study suggests that chum salmon spend approximately 6 days spawning. It is possible during this period of time, females have become territorial and may not move far from the redd site. The final JS model stream residence time estimates from POPAN 6 for females were 3 to 4 days. We could be recapturing females at a higher rate because they are territorial when spawning and the same general area was seined each week.

Male chum are not as stationary as females because after spawning they immediately move to find another mate (Lister and Harvey 1969, Schroder 1982). Floy tag recovery data suggest that males are more likely to be recovered at other sites as well. A total of 12 tagged male chum salmon were captured during seining activities at different locations, while no female chum salmon were captured at different locations. However, carcass recovery data did reveal some movement for females. A total of 22% (14/ 61) of the male chum salmon Floy tag recovered as carcasses were in areas other than they were tagged. For females chum salmon 4 of 34 (11%) carcasses, were recovered in areas other than where they were tagged.

Assumption (1) for the JS model is equal catchability of tagged and untagged fish and at these sites seining could be recapturing females at a higher rate because they are territorial when spawning and the same general area was seined each week. Therefore, previously tagged females may be more susceptible to tangle netting (capture), which would lead to a violation of assumption 1. If tagged males have a higher likelihood of mixing with untagged males, then using males only to estimate the population may not substantially violate assumption 1 (Parker et al. 2001). TEST 2 cannot detect violations of this assumption because these test are preformed on tagged animals only. The Hardy and Hamilton Creek sex ratio based on carcass recoveries were 1.8:1 in favor of males and are close to the JS sex ratio estimates from live seining. However, the carcass based sex ratios may be biased to females because they tend to defend the redd site until death and are often recovered as carcasses at a higher rate than males, which tend to move to another sight after spawning. Additional studies in residence time and chum salmon sex ratios are needed for Columbia River chum salmon.

Other Population Estimates

The JS model chum salmon population estimates obtained from seining data were compared to other population estimates obtained using previously employed standardized methods. Data on carcass tagging in 2002 was provided from Kelly Harlan (PSMFC) and live counts from Ken Keller (PSMFC). This data was reanalyzed for consistency in this report.

Petersen Estimate

Petersen estimates were made for the same three groups. The weekly seining and tagging was considered the capture event and the carcass surveys were considered the recapture event. The pooled Petersen estimate is consistent if the population is closed, it meets the assumptions similar to the JS model, and a constant proportion of the fish are marked or if a constant proportion of the carcasses are sampled. SPAS, a stratified population analysis software, was used to develop Petersen estimates and SE (Arnason et al. 1996). Based on radio tagging and Floy tag recoveries we know that the closure assumption was not completely met. The violation of this assumption appears to be smaller for the I-205 and Multnomah groups. For the Ives group we had substantial live and carcass recoveries in Hamilton, Hardy, and Duncan Creeks and it appears the closure assumption was most seriously violated for this group (Table 11).

The population estimates and their SE for the Petersen estimator and JS models are found in Table12. Separate estimates of males and females were not available for the Petersen estimate because samplers did not keep separate totals of carcasses by sex. Rawding and Glaser (in prep), Schwarz et al. (1993), Brookover et al. (1999), and Harding et al. (1999) have observed that population sizes from the Petersen estimator were consistently higher than those obtained from the JS population estimate. Both JS and Petersen estimates for two of our three groups are similar but not very precise due to few recoveries. After the fact it is possible that the closure assumption may not have been significantly violated at the Multnomah and I-205 sites, and equal mixing may have occurred making the Petersen estimate more consistent. The closure violation for the Ives group also manifests itself in the large difference between the JS and Petersen population estimates.

Table 12. Comparison of pooled Petersen and JS population estimates from live seining tagging for three mainstem Columbia River chum salmon spawning groups in 2002.

Group	Peterson Pop. Estimate	Peterson 95% CI	Jolly-Seber Pop. Estimate	Jolly-Seber 95% CI
Ives	20,166	15,415 – 24,917	3,179	2,886 – 3,472
Multnomah	2,506	1,341 – 3,690	1,282	846 – 1,642
I-205	3,928	2,274 – 5,581	3,468	3,116 – 3,820

JS Carcass Tagging

The same JS method was used to estimate the population based on carcass tagging. In this study the same protocols developed by McIssac (1977) were followed. Carcasses were recovered from the stream bank or shallow water, and all fish were examined for tags. Early in the season all fish were bio sampled and as the season progressed the bio sample rate decreased (Rick Heitz, PSMFC pers. comm.). Untagged carcasses were tagged with a vinyl disc on the inside of the opercle and released in the same location they were found. Any recoveries with a carcass tag were treated as loss on recovery and identified by removal of the caudal fin.

Carcass tagging estimates for the Multnomah and I-205 populations are 228 and 211, respectively (Table13). On December 3, the peak day of seining, 139 chum salmon at the Multnomah site were handled and the cumulative count of unique individual chum salmon handled over the season at this site is 282 fish. On December 2 at the I-205 site we handled 326 adult chum salmon and the cumulative season total was 780 fish. The carcass tagging estimates at these two sites are biased low, the minimum handle total from seining activities exceeded the carcass tagging population estimate for the Multnomah group, and both the peak handled and minimum handle totals exceed the carcass tagging population estimate for the I-205 group. This occurred because carcass sampling only occurred four times during the season due to resource and weather constraints.

Table 13. Comparison of JS population estimates from seining and carcass tagging for three mainstem Columbia River chum salmon spawning groups in 2002.

Group	Jolly-Seber (Carcass Tagging) Pop. Estimate	Jolly-Seber (Carcass Tagging) 95% CI	Jolly-Seber (Seining) Pop. Estimate	Jolly-Seber (Seining) 95% CI
Ives	4,232	4112 - 4352	3179	2886 - 3472
Multnomah	228	153 - 303	1282	846 - 1642
I-205	211	170 - 252	3468	3116 - 3820

The Ives Island carcass tagging study covered sections 1 through 4 and the survey crew collected 3,185 carcasses. The population estimate was precise at 4,232 and a 95% CI of +/- 120 under the full model. AIC indicated that this was the best model. The final JS estimate from seining was 3,179 with a 95% CI from 2,886 to 3,472. However, our seining estimate was based primarily on sampling in sections 2 and 4, and therefore the JS seining abundance estimate for the JS model should be less than the carcass tagging estimate that included two additional sections.

For the Ives Island group, the same five JS assumptions were examined using carcass tagging data. For seining, size and sex bias were examined using KS and χ^2 tests. Since carcasses were batch marked and no information other than a colored tag was noted during tagging and recovery, these tests were not performed. The GOF test was used to assess assumptions 1 and 2 (equal catchability and survival). Since the standard WDFW carcass tagging procedure is to treat recovered marked carcasses as loss on recovery the GOF tests from Pollock et al. (1990) as found in the program JOLLY were used because it was easier to incorporate loss on capture into the tests. The test 1 and 2 in JOLLY are similar to TEST 2 and 3 in RELEASE but use different algorithms. Since tagged fish are treated as loss on capture no results are available for test 1. Survival probabilities in test 2 were significant due to an increase in zi (recoveries after the first recovery period) over the period of the study. This result was significant (χ^2=75.5805, df=8, P=0.0000). These probably do not represent an increase in survival but instead, a decrease in sampling efficiency for carcasses as this occurred when the crew was sorting through over a thousand carcasses per week and/or potentially the carcasses were moving between locations due to an increase in the variation of daily discharge which occurred in mid December (Figure 2). Assumption 3 (handing mortality) was not considered since the fish were dead when tagged. The tag loss (assumption 4) could not be examined, since secondary marks or double tagging were not incorporated into the study design. Assumption 5 (instantaneous sampling) was met as carcasses were tagged immediately upon recovery and returned to the recovery site.

As with live seining JS estimates, assumptions 1 and 2 can only be tested with uniquely tagged fish. The most problematic assumption involved in carcass tagging is that tagged and untagged carcasses have equal catchability. Law (1994) reported that some biologists believe that estimates obtained from carcass tagging in large rivers may be too low because untagged carcasses may be deposited in deep or inaccessible areas and create a subpopulation that is never available for sampling. This certainly is a possibility in the mainstem Columbia River. In these cases it is essential for tagged carcasses to be released upstream of where they were recovered so that tagged and untagged carcasses can randomly mix (Boydstun 1994).

AUC

AUC is the primary methodology used to estimate chum salmon escapement in the Columbia River and its tributaries (Keller 2002, Hoffman 2001, Uusitalo 2003, Rawding 2003). AUC has proved to be a robust method for estimating salmon escapement (Nielson and Green 1981, English et al. 1992, Hilborn et al. 1999, and Parken et al. 2003). Although WDFW uses this methodology for chum salmon escapement estimates in Puget Sound (Ames 1984 and Haymes 2001), the robustness of this technique on the mainstem Columbia River is unknown. Salmon escapement using the AUC methodology is estimated:

$$E = AUC/RT \qquad (4)$$

where E = escapement, AUC = the total aggregate residence time or fish days obtained by plotting the number of fish observed against the day of the year and is estimated using a variety of algorithms, and RT (residence time) = the mean number of days that a fish spends in the survey area. The observed AUC is often adjusted by dividing seasonal or daily counts by the observation efficiency, which is a measure of how accurate surveyors are at counting all of the fish present in the survey section.

The Columbia River in the vicinity of chum salmon spawning sites ranges from 750 feet in width near the Hamilton, Ives and Pierce Islands to over a mile wide near the mouth of Multnomah Creek. River bottom contours indicate the bottom can become too deep to observe fish in a very short distance from the shoreline. Strong winds, especially at the Multnomah site, can make counting chum salmon difficult as they often limit an observer's ability to see below the surface from the bow of a boat. The ability to detect chum salmon is affected by the turbidity of the water. Turbidity, as measured by secchi disk readings at Bonneville Dam in 2002 averaged 6.3 feet from November 1 to December 31 and ranged from 4 to 7 feet (COE 2003). Residence time for chum salmon in the mainstem Columbia River has not been measured. WDFW uses a residence time of 10 days in Puget Sound based on three studies from Ames (1984), which is the same residence time used by PSMFC for estimates in the Columbia River (Keller 2002). Rawding (2003) reported that residence time in Columbia River tributaries is approximately 9 days but varied between 4-16 days. Perrin et al (1990) and Hilborn et al. (1999) indicate that residence time is also highly variable between years. The residence time and observer efficiency for chum salmon spawning in the mainstem Columbia River is currently unknown.

Typically, WDFW estimates the AUC by manually drawing a line through the data (Ames 1984). The biologist uses all the available information including plots of live and dead fish counts, and recorded water conditions during the survey. Based on experience and professional judgment, a spawner curve is estimated. The AUC is then divided by mean residence time (10 days) to estimate escapement. These same procedures are used by PSMFC in estimating Columbia River escapement. Since there is subjectivity in this methodology, we calculated the AUC using the standard trapezoidal approximation

$$AUC = \Sigma (t_i - t_{i-1}) * ((x_i - x_{i-1})/2) \quad (5)$$

where t_i = the day of the year and x_i = the number of salmon observed for the ith survey (English et al. 1992).

The boat counts and AUC estimate for the three groups are found in Figure 7. Surveys for the Ives Island group were conducted twice per week through late November and then weekly until the end of spawning in late December. Counts were more sporadic at the other two sites due to weather conditions and limited resources. At all sites counts did not always start prior to spawning and continue through the end of the season. We assumed that no chum salmon arrived prior to November 1 and spawning was complete by December 31. There are 25,430, 9,750, and 12,370 fish/days for Ives Island, Multnomah, and I-205 groups, respectively. Assuming the standard residence time of 10 days, the population estimates are 2,543, 975, and 1,237 fish, respectively. Estimates of uncertainty are not available for this methodology. These AUC escapement estimates are approximately 36% to 76% of the JS population estimates from seining. These AUC estimates assume 100% observer efficiency and 10 days residence time. It appears that either or both these assumptions are not valid for mainstem Columbia River spawners.

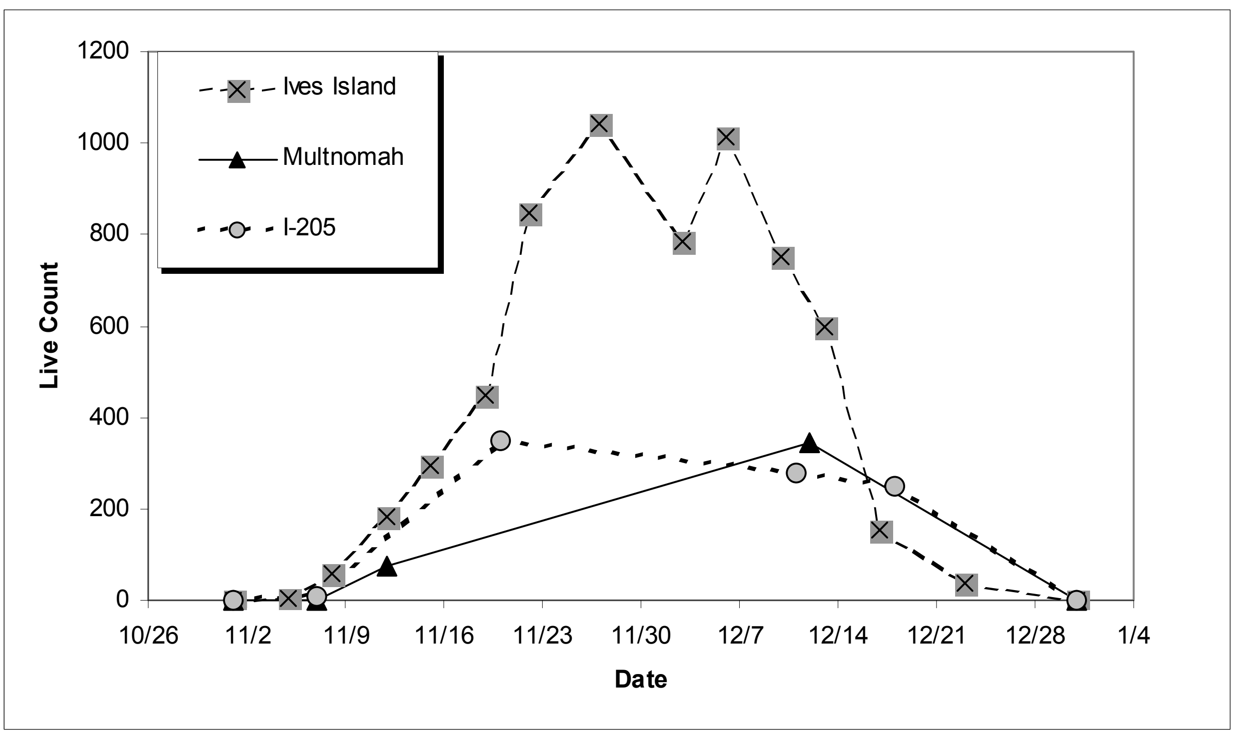

Figure 7. Boat counts and a trapezoidal approximation of AUC for chum salmon in the Ives, Multnomah, and I-205 groups in 2002.

AUC Calibrated with Mark-Recapture Studies

Fisheries managers using AUC methods have calibrated them to counts of known escapement at weirs and estimates of escapement from mark-recapture experiments due to their inherent uncertainty, especially in the observer efficiency and residence time parameters. Ames (1984) used counts from weirs in small streams in Puget Sound, and assumed 100% observer efficiency to determine residence time. Bue et al. (1998) used weirs on streams in Prince William Sound, independent estimates of residence time, and independent estimates of observer efficiency to compare the accuracy of AUC estimates to weir counts. Hilborn et al. (1999) then developed MLE to estimate uncertainty in the AUC method on these same Alaskan streams based on an assumed normal or beta arrival distribution and various error structures. Parken et al. (2003) used a bootstrap procedure that follows the trapezoidal AUC method and incorporates uncertainty associated with fish counts, the shape of the spawners curve, observer efficiency, and residence time. These were calibrated from a mark-recapture study. Estimates of uncertainty fish counts were obtained by scheduling replicate counts and uncertainty in observer efficiency and residence time was a measure of the variability in residence time (RT) calculated from the equation:

$$RT_i = AUC_i \;/\; N_{iMR} \qquad (6)$$

where RT_i = residence time, AUC_i = area under the curve measured fish days and N_{iMR} = the population estimate from mark-recapture. If fisheries and hydro managers plan to use the AUC method to estimate chum salmon populations, then independent mark-recapture studies must be conducted simultaneously to develop accurate and unbiased estimates of observer efficiency, residence time, and ultimately chum salmon spawning escapement. Parken et al.(2003) provides an excellent framework for such a study design.

AUC escapement estimate at Ives Island were developed using a combination of the methods of Parken et al. (2003) and Hilborn et al. (1999). Live counts from boat observation and the cumulative estimates of dead salmon (Di) from the JS carcass model (Figure 8) were plotted. We assumed a normal distribution for arrivals and deaths, a normal error structure for the statistical model, and minimized the likelihood to the live count and cumulative carcass estimate (Hilborn et al. 1999 equations 5, 6, 9, and 10). We used MLE methods to estimate escapement, standard deviation of escapement, mean date of arrival, standard deviation of mean date of arrival, and residence time by simultaneously fitting the normal distribution to the live count data and the cumulative normal distribution to carcass data. Observation efficiency was 100% so the residence time includes a correction for observation efficiency (Parken et al. 2003). The results indicate an AUC calibrated escapement of 4,291 fish.

For each level of escapement the likelihood profile for escapement was estimated by searching over all possible nuisance parameters (Venzon and Moolgavker 1988). The chi-square probability distribution was plotted in funnel graphs (Schnute 1987) and confidence intervals were estimated from the graphs. For example, the 95%CI are found at the points where the confidence interval crosses 95% probability line. The 95% CI for the Ives Island calibrated AUC was +/- 154 fish (Figure 8). Since the carcass tagging data was used to develop the calibrated AUC estimate, both population estimates are similar. The estimates of residence time was 6.1 days with 95% CI (+/-0.75 days). Parken et al. (2003) and Hilborn et al. (1999) indicate this method of developing AUC estimates is robust and it appears so for the Ives population.

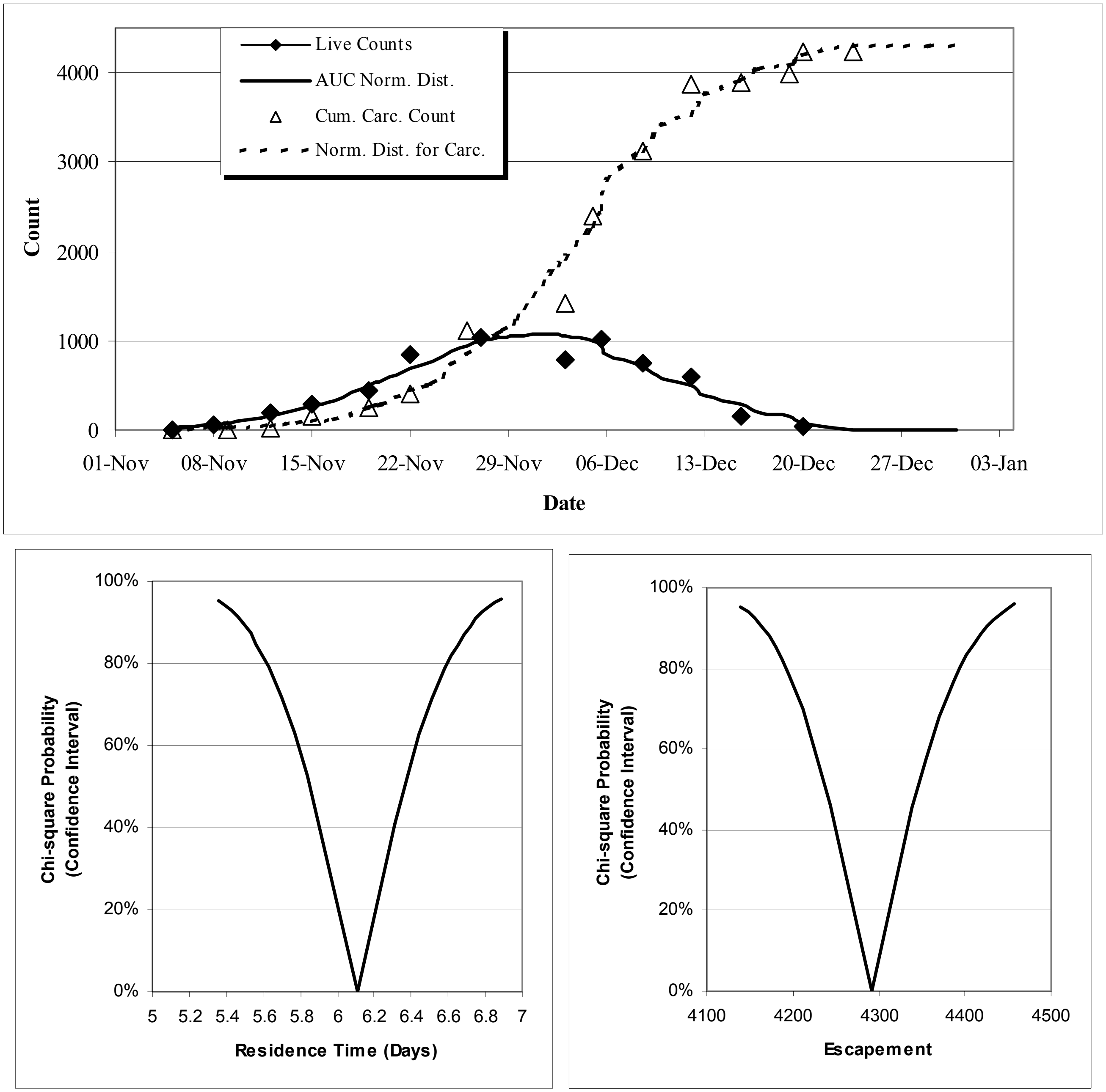

Figure 8. Plot of live counts and cumulative carcass counts obtained from JS carcass tagging (top), Likelihood Profile for residence time (bottom left) and escapement (bottom right) estimates assuming a normal distribution and normal error structure.

Precision

The individual population estimates and their precision are found in Table 12. Robson and Regier (1964) recommended that population estimates be +/- 25% for management purposes and

+/- 10% for research. WDFW recommends that the precision of population estimates be +/10% because of a number of legal and policy issues. Columbia River chum salmon are listed under the ESA and accurate and precise populations estimates will be required to de-list this population. Currently, there is insufficient water in the Columbia River to meet societal demands. Annual and daily water management decisions are being made that have potential negative impacts to this population especially the subgroups that spawn in the mainstem Columbia River. In the absence of accurate and precise chum salmon information decision makers will continue to make less informed decisions, which will continue to put this species at risk unless managers adopt risk adverse policies. Precise population estimates will allow the development of a more informed water policy on the Columbia River.

Simulations were conducted to better understand the minimum sampling requirements for the JS seining model with guidelines of 10 recaptures per period, and 95% CI near +/-10%. Since the average residence time from this project is less than 7 days most tagged fish are dying before they can be recovered when sampling is conducted weekly. This residence time is similar to studies (Lister and Harvey 1969, Lister et al. 1980, and Hillson 2002 and 2003). Based on existing research and 2002 field data, seining should be conducted twice per week, ever three to four days to increase the recovery rate for tagged fish. Also, Schwarz et al (1993) notes that "the use of carcass recoveries and normal recoveries will not lead to serious bias if the number of carcasses remain small or if carcasses do not remain in the stream for long periods after death." Simulations suggest that sampling twice per week and including carcasses, will ensure ten recaptures per week except during the initial and final sampling periods, and 95% CI will approach +/-10%.

In 2002, PSMFC and ODFW tagged 3,185 chum salmon carcasses captured at Ives Island. Since it is time consuming to tag these carcasses, tagging only a portion of the carcasses was investigated. We assumed the population would be 1,000 males and 1,000 females and estimates were required for each sex. Surveys would take place twice per week, but data could be pooled to weekly estimates with little bias (Hargrove and Borland 1995). We assumed a 50% capture rate, survival of a fresh carcasses capture in week 1 was 90% from week 1 to 2, survival of decayed carcasses missed in week one but recovered in week 2 was 67% from week 2-3, and survival of very decayed carcasses missed in week one but recovered in week 3 was 33% from week 3-4. All carcasses missed from week 1 had completely decomposed by week 4 and were unsamplable. These carcass decay assumptions were similar to those used by Law (1994) except our decomposition rate was slower based on the 2002 data. Since tagging every carcass requires additional time, possible changes to the tag rate were explored that would still meet the precision goal of 95% CI (+/- 10%) and the minimum recaptures of 10 for most of the study period. Tagging rates of 100%, 50% 33% and 20% were modeled and 95% CI were 2%, 4%, 8% and 10% respectively. In this simulation recaptures (mi and ri) remained greater than 10 except at the 20% tag rate. Model results are found in Figure 9 and we recommend a 33% tag rate to ensure ri>10 for most sample periods. If carcass tagging is done at the Multnomah and/or I-205 site all carcasses must be tagged to address low and uncertain tagging and recovery rates.

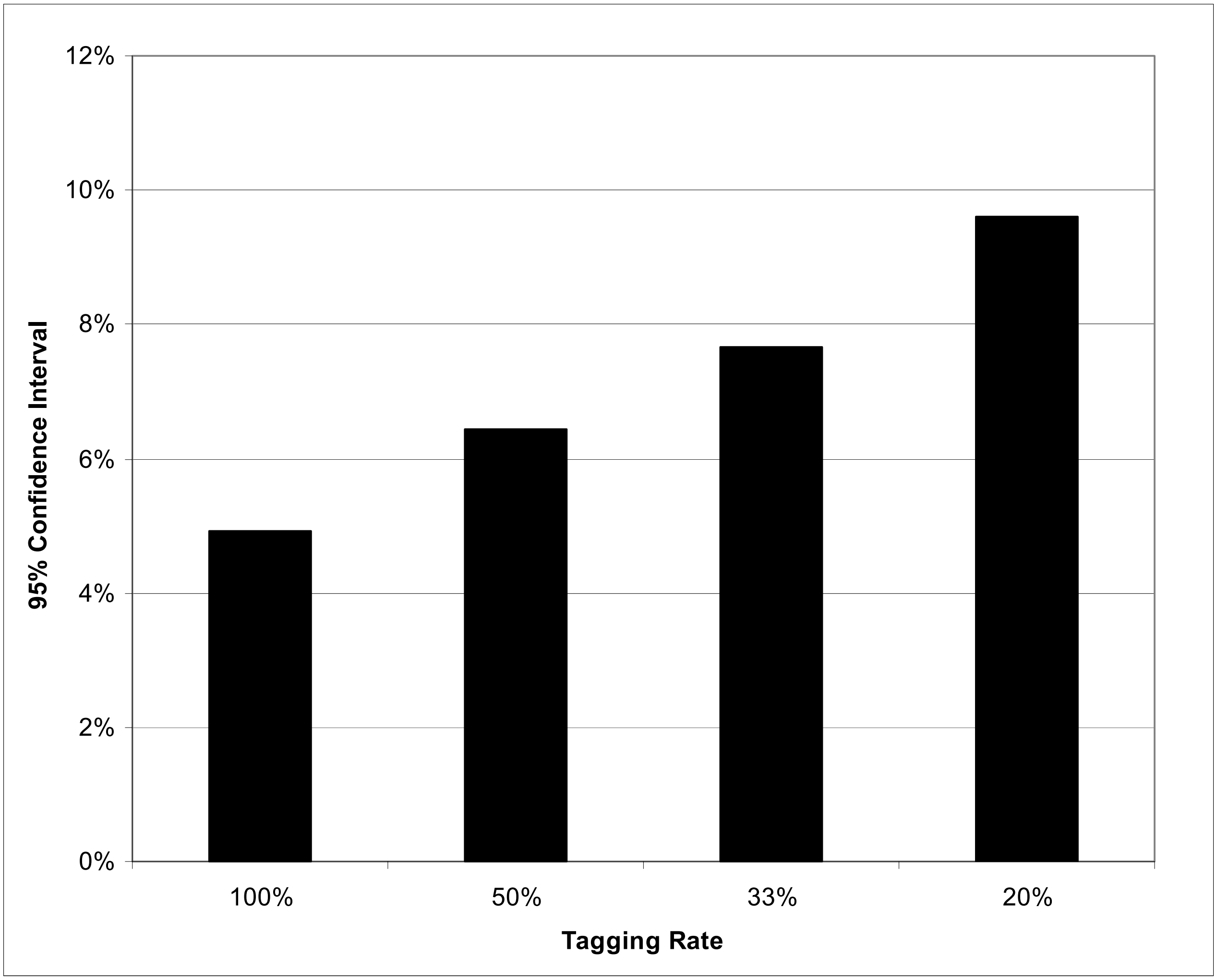

Figure 9. Estimated 95% CI from a simulation assuming a population size of 1,000 fish, 50% recovery rate, and various carcass tagging rates.

Hill (1997) and Bue et al. (1998) showed that uncertainty in AUC estimates increased with the distance between observations. Hill (1997) indicated that observation frequency should increase around the expected peak of spawning to detect the peak. In 2002, Ives Island live counts were conducted twice per week through the last week in November and then weekly. Preliminary assessment indicate that counts should be initiated by November 1 and be conducted weekly until November 24. From November 24 to December 7, count should be conducted twice per week. After December 7 if the peak has been identified, count frequency could be reduced to once per week until the end of December or until spawning is completed. These recommendations can be viewed as a minimum to develop escapement estimates and it is possible more frequent counting is needed for in-season water allocation decisions.

Population estimates may be biased even though the best field sampling protocols were followed. Field data from 2002 can be used to investigate the source, magnitude, and direction of the bias using simulation models. This area of chum salmon population estimation needs additional work.

Summary

Our primary motivation in developing accurate and precise escapement estimates of chum salmon spawning in the mainstem Columbia River is to evaluate the contribution of adults from the Duncan Creek re-introduction program to mainstem spawning. Additional motivation is to accurately estimate escapement so that managers make informed water allocation decisions, NMFS can determine status relative to the ESA, and the region can incorporate the best information in developing recovery plans to reduce risks to chum salmon populations. While successful in our primary objective of broodstock collection for Duncan Creek re-introduction, we were less successful in estimating the population size of mainstem spawners. In the first year, we did not tag and/or recover as many fish as we would have liked, and because of this sparse data, the accuracy and precision of our estimates suffered. Despite these shortfalls, we developed a range of reasonable estimates. The final estimates and SE from seining using the JS model are 3,179 (150), 1,269 (216), and 3,468 (180) for Ives, Multnomah, and I-205 groups, respectively. These are much higher than population estimates from other AUC and carcass tagging methods at the Multnomah and I-205 sites. The carcass tagging estimate for Ives Island is 4,232 (79) and is a more accurate measure of population size at this site since sampling occurred at all sites.

Recommendations

The precision of mark-recapture population estimates as measured by the 95% CI, ranged from 10% to 34%. WDFW recommends the 95% CI target to be +/-10%. Simulations suggest that with additional resources, the precision of the population estimates could be reduced from greater than +/- 34% to near +/-10%. mainstem Columbia River chum salmon escapement estimates were funded by BPA (Chum Salmon Salvage/Duncan Creek Re-introduction Projects) and by WDFW. Current level funding in these projects will not allow precise and accurate estimates of chum salmon spawning in the mainstem Columbia River. WDFW recommends that an additional field crew with a jet sled be used to increase sampling frequency and assistance from a biometrician be incorporated into this mainstem chum salmon population escapement project. If personnel cannot be transferred from other projects, we suggest funding for this project increase to $50,000/year.

Currently, mark-recapture experiments provide the only framework for accurate estimates of mainstem Columbia River escapement and precision. All population estimates should start from a global population model compatible with the biology of the species studied. The underlying assumptions of mark-recapture need to be examined using hypothesis testing within a statistical framework including GOF tests. A more parsimonious model should be selected using AIC. To address model uncertainty, MLEs of model parameters with estimates of precision must be reported. The Jolly-Seber model is appropriate for this type of estimation and analysis.

It is imperative to use individual tags, so that individual capture histories can be developed. Individual histories are needed to develop GOF tests. Without individual tags, GOF tests cannot be used to assess if basic mark-recapture assumptions have been violated. We recommend that individual tags be applied to live fish for standard JS model estimates and to carcasses if JS estimates will be developed from carcass tagging. To reduce the probability of assigning marked only fish to the wrong capture history, secondary marks should be rotated by sample period, and fish with missing tags should be retagged. If tag loss remains a problem, likelihoods for tag loss should be incorporated into the population and variance estimates.

Assumptions about equal catchability of tagged and untagged chum salmon need to be validated. Seining should encompass the entire spawning area rather than where abundance is highest. If the entire area is surveyed mixing of tagged and untagged fish should occur. Radio tagging could also be used to help assess this assumption. Seber (1982) recommends that recaptures (mi) be at least 10 per sample period. While this occurred at times when sexes were combined; it did not occur when separate population estimates were calculated by sex. Recovery rates by sex may be significantly different, and sampling effort should include one extra day per site per week to ensure that recaptures (mi) by sex remain above 10. Carcass sampling should occur on seining days if possible or on adjacent days.

Continued seining for broodstock collection as part of the Duncan Creek re-introduction and mainstem salvage program is necessary and continued carcass recoveries as part of an otolith and CWT recovery program. Therefore, we recommend that data from mark-recapture estimates be collected in conjunction with these programs. Seining for the Ives group should include all four sites (bay, slough, outer island, and boat ramp), and sampling should extend throughout the chum spawning period at all locations. Schwarz et al. (1993) suggested that carcasses be included in JS model population estimates as long as they were small compared to the lives, and/or as long as recoveries were fresh carcasses. There was little change in their coho salmon escapement estimate with and without carcasses. However, the precision of the estimates increased when carcasses were included.

To address potential bias in future estimates we recommend that spawning sites be seined twice per week, since estimates of stream residence time are less than one week. Carcass surveys in the Ives Island area should continue twice per week. Simulations suggest that the tagging rate for carcasses can be reduced from every fish to every third fish, without a loss in precision as long as catch rates remain at 50% and the population size approaches 1,000. To test JS model assumption we suggest that marked carcasses be returned to the stream after their initial recapture but can be removed after their second capture. Limited data from the carcass surveys at Multnomah and I-205 suggested that recapture probabilities are lower and surveys should be conducted twice per week and possibly included with the seining operation.

If AUC estimates are to continue, surveys should be conducted weekly under conditions where observer efficiency is highest (no wind and clear water). Frequency should be increased to every 3-5 days near the peak spawning time (generally between late November and early December). If AUC is to be used to estimate chum salmon escapement in the mainstem Columbia River, then observer efficiency and residence time must be independently estimated for each spawning area. If AUC surveys are conducted in conjunction with this mark-recapture work, then we may be able to estimate the uncertainty in observer efficiency and residence time independently.

We estimated chum populations by site. However, we did not incorporate data when fish tagged at one site were recovered at other sites. Additional analysis should explore a meta-population population estimate with multi-site models including Hamilton and Hardy Creek's spawning groups.

BPA funded Columbia River chum salmon projects: 1)Evaluation of fall chinook and chum salmon spawning below the Bonneville, The Dalles, Johns Day, and McNary Dams (project # 99-003-01/99-003-02), 2) Evaluate factors limiting Columbia River Gorge chum salmon populations (project # 2000-01200), and 3) Reintroduction of Lower Columbia River chum salmon into Duncan Creek (project # 2000105300) include an accurate estimate of chum salmon escapement in their study goals. The current organizational and contracting structure has not provided an integrated and coordinated approach for chum salmon population estimates. WDFW suggests that coordination between all chum salmon projects increase to promote development of statistically rigorous study designs for adult and juvenile chum salmon population monitoring.

Acknowledgments

This research was supported by BPA and WDFW. We would like to thank the field staff of PSMFC and WDFW for collecting the seining data used in this analysis including Ken Keller (PSMFC), Dwayne Fossen (PSMFC), Cameron Black (PSMFC), Steve VanderPloeg (WDFW), and Charlie Cochran (WDFW). Rick Heitz, (PSMFC), Brian McNamarra (PSMFC), Roy Clark (ODFW), and Robert Brooks (ODFW) collected live counts and conducted carcass tagging. Ken Keller (PSMFC), and Kelly Harlan (PSMFC) provided summarized live counts and carcass data for these populations. Nancy Uusitalo (USFWS) provided information on tagged recoveries in Hamilton Springs and Hardy Creek. Robin Ehlke and Nancy Uusitilo provided preliminary information about radio tag movements. Joe Hymer (PSMFC) and BPA contract officers, Nic Lane and Ben Zelinsky, provided contract oversight for the Duncan Creek project. Travis Butcher (PSMFC Streamnet Program) and Chris McCarty (Fish Passage Center) provided maps of the Columbia River. The authors would like to thank Jennifer Amren, Deb Hillson, and Bryce Glaser for comments and suggestions on an earlier draft of this paper.

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