Survival rates of coho (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*) released from hatcheries on the U.S. and Canadian Pacific coast 1972–1998, with respect to climate and habitat effects

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A thesis submitted in partial fulfillment of the
requirements for the degree of

Master of Science

University of Washington

2002

School of Aquatic and Fishery Sciences

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Abstract

Survival rates of coho (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*) released from hatcheries on the U.S. and Canadian Pacific coast 1972–1998, with respect to climate and habitat effects

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Smolt-to-adult survival rates were estimated for 18 659 coho and chinook coded wire tag (CWT) groups released in 1972–1998 from 206 hatcheries on the U.S. and Canadian Pacific coast. Survival rates of 153 wild CWT groups showed similar trends as those of hatchery fish. The long-term trend for both coho and chinook was a decline in all regions south of Alaska, while survival rates increased in Alaska. Regional and annual variation explained 46% of the total variation for coho, 34% for fall chinook, and 42% for spring chinook. Regression analysis was used to explore the relationship between survival rate and climate during the year of release, and the variable that showed the

strongest relationship was summer sea surface temperature (SST) at the place where the fish reach the ocean. The estimated relationship is quadratic in log space, with an optimum around 13°C for coho (95% confidence interval: 12.87°C–13.08°C) and fall chinook (12.44°C–13.42°C), but such an optimum could not be accurately determined for spring chinook (2.56°C–12.24°C). The SST variable alone explained 41% of the regional and annual variation of coho survival rates, only 12% for fall chinook, but 44% for spring chinook due to low survival rates at high SST values. Little is known about the ecological dynamics that link SST and survival rate, but SST is highly correlated with a suite of physical and biological factors in the ocean. There has been a long-term increase in SST from the early 1970s to the late 1990s, corresponding to the declining survival rates south of Alaska and increasing survival rates in Alaska. During a cooler period in the mid 1980s, survival rates increased for some years south of Alaska, but decreased in Alaska. These results suggest that the decline in wild salmon abundance in the 1990s was due in considerable part to changes in ocean conditions and increases in wild stock abundance may be expected if ocean conditions change.

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Acknowledgements

I would like to thank the members of my supervisory committee, Profs. Ray Hilborn, John Skalski, and Gordon Swartzman for their guidance and influential ideas. In particular I am very grateful to Ray Hilborn for his constant support and for providing me with invaluable research opportunities on three continents.

I would also like to thank Ken Johnson, Jim Longwill, and Dan Webb for their help with the coded wire tag database reconstruction, clarifications, and subsequent updates. Finally I am indebted to Steven Hare, Claribel Coronado, Laurie Weitkamp, and Brenda Adkins for supplying climate and hatchery data, as well as helpful advice.

1 INTRODUCTION

1.1 Salmon Survival

The survival of salmon is a topic of intense debate throughout the Pacific coast of North America among decision makers, natural scientists, and the public at large. Revenues from catches are an important part of regional economies and abundant salmon runs are also viewed as an indicator of relatively untouched ecosystems.

Artificial production of salmon has been practiced on the Pacific Coast since the late 1800s, but it was not until the 1960s and 1970s that the number of hatcheries and their release output increased dramatically (Wahle and Smith 1979). This was a response to dwindling spawner returns and today more than half of the salmon catches in the Pacific Northwest are of hatchery origin, but in Alaska the opposite is true, where most runs consist of wild spawners in pristine watersheds (NRC 1996). There is little doubt that large-scale releases of hatchery-reared salmon can pose a threat to wild populations, by means of competition, predation, genetic dilution, and increased fishing pressure (Lichatowich 1987, Goodman 1990, Hilborn 1992, NRC 1996, Noakes et al. 2000, Levin et al. 2001). Whether hatcheries should be operated or not is a topic outside of the study presented here, but the extensive tagging program maintained by the hatcheries provides a large source of data for analyzing survival rates.

The number of returning spawners, wild and hatchery-reared, fluctuates considerably between years but in most areas the long-term trend is that the runs have diminished and in many cases gone extinct (NRC 1996). The dynamics behind those changes are often far from understood and due to the complex salmon life cycle their survival can be impacted by a multitude of physical and biological factors in local watersheds and the ocean.

1.2 Factors Affecting Survival Rates of Hatchery-reared Salmon

In this overview, various factors explored in the literature are sorted by the salmon life stage it affects, from hatchery smolt release until adulthood. Survival rates have been shown to increase with the average smolt weight at release (Bilton et al. 1982, Green and Macdonald 1987). Trends in coho and chinook survival rates differ between geographical regions (Coronado 1995, Coronado and Hilborn 1998), but no relationship was found between survival rates and the number of years a hatchery has operated (Coronado 1995).

Environmental effects during the downstream migration can be expected to be river-specific, but both Scarnecchia (1981) and Skalski (1996) describe a positive relationship between survival rates and river flow. Holtby (1988) and Baker et al. (1995) report a negative relationship between survival rates and river temperatures. The mortality rate of smolts crossing large dams in the Columbia Basin has been estimated around 5–10% per dam, depending on the dam in question (Mathur et al.

1996, Skalski 1998, Skalski et al. 1998), and in his analysis of declining survival rates with distance upstream, Newman (1997) relates those mortalities primarily to dams in the study area.

Smolts are subject to considerable mortalities in estuaries and in the ocean just outside the estuaries (Parker 1971, Mathews and Buckley 1976, Macdonald et al. 1988) where predation appears to be the dominating factor, as opposed to food shortage (Fisher and Pearcy 1988, Mathews and Ishida 1989, Pearcy 1992). Density-dependence during the smolt and ocean phases, meaning lower survival rates when abundance is high, is likely to differ between watersheds and seems to play a greater role in years when survival rates are low in general (McGie 1984, Emlen et al. 1990, Levin 2001).

Many oceanographic variables in the North Pacific are correlated with each other, for example strong upwelling causes lower sea surface temperature (SST) and this combination is in turn correlated with high survival rates of salmon (Scarnecchia 1981, McGie 1984, Nickelson 1986, Johnson 1988, Emlen et al. 1990, Holtby et al. 1990). These and other oceanographic variables are related to a low atmospheric pressure system termed the Aleutian Low, which is known to shift on a decadal scale and markedly alter marine ecosystems in the North Pacific, a phenomenon which was last known to occur during the winter of 1976/1977 (Beamish 1993, Beamish and Buillon 1993, Francis and Hare 1994, Beamish et al. 1997, Gargett 1997, Mantua et al. 1997, Francis et al. 1998, Beamish et al. 1999, Hare et al. 1999, Beamish et al. 2000). These studies have shown that the consequences of such shifts for salmon survival rates are the opposite in Alaska compared with the Pacific Northwest, which implies that there may exist an “optimal window” of climate conditions, with lower survival rates on both extremes. The search for this optimal window characterizes recent studies of climate and survival rates (Ryding and Skalski 1999, Cole 2000, Hobday and Boehlert 2001), but the reported patterns tend to look complicated and inconsistent between and within studies.

1.3 Regression Models

Most of the studies reviewed above are based on models that fall into two categories: linear and nonlinear regression models. Cormack and Skalski (1992) review linear models used in the analysis of release and recovery data, demonstrating how one model can be rearranged algebraically to have either survival rate or number of recovered tags as the response variable. Survival rate is often log-transformed and predictor variables can be incorporated as quadratic terms to allow the fitted survival rate to optimize at an intermediate predictor value.

Examples of linear models with normal error structure are found in Bilton et al. (1982), Nickelson (1986), and Cole (2000). Another approach is to assume Poisson error structure, as recommended by Green and Macdonald (1987), Cormack and Skalski (1992), and Pascual (1993), later applied by Coronado (1995) and Coronado and Hilborn (1998). Linear models have also been developed with binomial error structure (Baker et al. 1995, Newman 1997).

Nonlinear multinomial likelihood models are fitted to release and recovery data at the most disaggregated level, recovery counts stratified by release groups and time. This approach partitions the survival rate of each group by time and seems especially appropriate when the number of release groups is not overwhelming (Mathur et al. 1996, Skalski 1996, Ryding and Skalski 1999) and for analyzing passive integrated transponder (PIT) tag data, but these tags transmit radio signals, allowing repeated "recoveries" without killing the fish (Skalski et al. 1998, Skalski et al. 2001).

1.4 Research Outline

The objectives of this study are to describe the observed spatial and temporal patterns in survival rate estimates of coho and chinook salmon and then explore how these patterns relate to climate and habitat variables. Coho and chinook are selected because the coded wire tag (CWT) program has primarily involved tagging of those two species. The geographical locations of the releasing hatcheries range from California in the south to Alaska in the north and the release years are 1972 through 1998. Generalized linear models (GLM) are fitted with survival rate as the response variable, in search of a combination of predictor variables that can explain the survival rate patterns.

Survival rate is essentially defined as the proportion of individuals that survives from smolt release to adulthood, and can therefore be seen as the product of freshwater survival rate and marine survival rate. Bradford (1995) analyzed how survival rate can be partitioned between salmon life stages, but in the CWT data the freshwater and marine components are inseperable. Regression analysis provides an approach to quantify how and to which extent predictor variables relate with the overall survival rate, but such relationships do not necessarily reflect simple causal linkages.

The data used in this study are from hatchery-reared salmon, so extrapolating the results to wild populations can be dubious in many cases. However, the CWT database does contain a small amount of data from wild smolt tagging studies and subsequent recoveries, and these data are briefly looked at in Section 3.5 of this study. Results from the comparison studies of Nickelson (1986), Emlen et al. (1990), and Coronado (1995), although on a coarse scale, imply that survival rates of wild salmon are slightly higher than that of hatchery-reared salmon, but the temporal patterns are similar.

The fundamental biological difference between wild and hatchery salmon is not the smolt-to-adult part of the life cycle, but rather the passing of generations, the “adult-to-smolt” part. In order to produce their progeny, wild populations have to escape fisheries and reach spawning grounds of sufficient habitat quality, and examples of habitat quality assessments can be found in Healey (1991), Sandercock (1991), NRC (1996), Roni and Quinn (2001), and Sharma and Hilborn (2001). At any rate, the economic importance and controversy surrounding hatchery-reared salmon certainly makes their survival dynamics interesting in their own right.

This study is a direct continuation of Coronado’s (1995) work, whose objectives and methods were comparable. With this continuation, six more years of release and recovery data are appended, but of greater importance is the addition of habitat and climate datasets used as candidate predictor variables in the regression analysis.

2 DATA AND METHODS

2.1 Coho, Fall Chinook, and Spring Chinook

The life history patterns of coho and chinook have been summarized by Healey (1991) and Sandercock (1991), where they describe regional variation as well as general trends. In this study, the age of hatchery smolts in years is calculated by subtracting the release year from the brood year. Hatchery releases of 2-year-old coho smolts typically take place in the spring, at the same time as many of their wild counterparts are migrating downstream towards the ocean. Almost all of the tag recoveries take place when the fish return as adults one year later (Table 1).

Chinook salmon show more complicated life history patterns and it is on the basis of the spawning run timing that they are commonly divided into two types: fall chinook, or ocean-type, and spring chinook, or stream-type (Gilbert 1913). The geographical distribution of wild populations (Taylor 1990) is also mimicked by hatcheries, in that fall chinook smolts are primarily released south of 56°N and not far upstream, while spring chinook smolts dominate the releases north of 56°N, as well as in the upper Columbia Basin. Fall chinook smolts are generally released 1 year old in the spring and are mainly recovered two years later, while spring chinook smolts are released 2 years old and mainly recovered two years later, at the age of 4, as shown in Table 1.

2.2 Coded Wire Tag (CWT) Data

Coded wire tags (Jefferts et al. 1963) are 1.0 mm long metallic wires that are implanted in the nasal cartilage of juvenile salmonids shortly before release from hatcheries (Figure 1). The wire tags are engraved with binary coded information unique for a specific smolt release group. Typically, a release group would consist of around 100 000 individuals and of those, around 10 000 are tagged and their adipose fin is clipped off.

When the salmon return from the ocean as adults, adipose-clipped individuals are recognized as tagged and their heads are returned to state agencies for analysis (Johnson 1990). Most of the recoveries come from commercial landings, where random samples are taken at ports, but samples are also taken from recreational catches, in addition to voluntary returns from anglers. Finally, tagged adults that escape fishing are recovered at hatcheries and in organized surveys of nearby spawning grounds. To represent the estimated number of tagged fish surviving to adulthood, the actual recoveries are expanded by dividing by the corresponding sample fraction.

Recovered tag codes are entered into a database, which contains information about where and when that salmon was released, as well as other characteristics of that release group. A section of the binary code engraved in each tag is used for validating the rest of the code, thus a predefined set of rules minimizes the probability of misreading. The CWT database is maintained by the Pacific States Marine Fisheries Commission (PSMFC) in Oregon and serves fisheries agencies as an important source of information about salmonid stocks. Although PSMFC offers a query interface on the web at http://www.rmis.org, a local database was reconstructed on a personal computer (last updated 13 July 2001) for the purposes of this study. The reconstructed database (Figure 2) consists of three main tables containing the CWT data: hatcheries, releases and recoveries. Thorough database definitions are specified in a manual published by PSMFC (1998), but the relevant fields are explained in the Glossary.

Not all release groups are useful for analyzing survival rates and data filtering was performed in two steps, first at the release group level (filters 1–3) and then at the hatchery level (filters 4–5):

1. Brood year

   The earliest years of the CWT data consist of erratic initial releases which are excluded from this study, as are the most recent brood years whose recoveries have not made it into the database yet. Coho brood years ≥1970 and ≤1996, fall chinook ≥1971 and ≤1995, and spring chinook ≥1971 and ≤1994.

2. Number of tagged smolts

   Release groups with less than 1000 tagged individuals are excluded, as their scarce recoveries carry virtually no information about survival rate.

3. Smolt weight

   A handful of release groups lack information about the average weight of tagged smolts and are excluded, in order to use that data as a candidate predictor variable.

4. Hatchery release site

   Only hatcheries releasing into freshwater are included, since few but diverse facilities conduct marine releases with highly varying results, not likely to clarify the overall trends.

5. Hatchery activity level

   Fulfilling all of the filters above, the releasing hatchery is included only if it has released a total of ≥10 CWT groups and done so over the course of more than a single year.

The resulting dataset (Table 2) consists of 18 659 coho and chinook CWT groups released from 206 hatcheries, some of which release both coho and chinook. The age at release is used to distinguish between fall chinook and spring chinook groups in the database. The hatchery locations are identified in Figures 3 through 7, and Appendix A contains specific hatchery information.

2.3 Estimation of Survival Rate

As noted earlier, survival rate is essentially defined as the proportion of individuals that survives from smolt release to adulthood. Because the age distribution at recovery varies between regions, recoveries are transformed to a standard age before the survival rate is estimated. This will allow a meaningful comparison of survival rates between regions.

The standard age is defined as the median age at recovery; 3 years old for coho and fall chinook, and 4 years old for spring chinook. Recoveries of younger or older individuals are transformed, based on natural mortality rates (Table 3) used by Argue et al. (1983), CTC (1989), and Coronado and Hilborn (1998). As an example, a recovery of 10 three-year-old spring chinook is transformed into 7 implied four-year-olds, reflecting that if they had stayed in the ocean for another year, they would have been subject to natural mortality rate $m_3 = 0.3$. For the sake of clarity we define a dummy variable $s_a = 1 - m_a$ to lay out the general equation to transform recoveries of all age classes into the implied number of fish at the standard age:

$$Implied = C_1 s_1 s_2 + C_2 s_2 + C_3 + \frac{C_4}{s_3} + \frac{C_5}{s_3 s_4} + \cdots + \frac{C_{max}}{s_3 s_4 \cdots s_{max-1}} \qquad \text{(Eq. 1)}$$

for coho and fall chinook, and

$$Implied = C_1 s_1 s_2 s_3 + C_2 s_2 s_3 + C_3 s_3 + C_4 + \frac{C_5}{s_4} + \frac{C_6}{s_4 s_5} + \cdots + \frac{C_{max}}{s_4 s_5 \cdots s_{max-1}} \qquad \text{(Eq. 2)}$$

for spring chinook.

Implied is the number of implied recoveries at the standard age, C_a is the number of expanded recoveries at age a, and s_a is the assumed survival rate in the ocean from age $a-1$ to a. The survival rate of each CWT release group is then calculated as:

$$Survival = \frac{Implied}{Tagged} \qquad \text{(Eq. 3)}$$

where *Tagged* is the number of individuals tagged in that CWT release group.

The average survival rate of CWT groups is listed by hatchery in Appendix B. Being a ratio, a high survival rate of a certain CWT group does not necessarily imply that the returning run was of great magnitude, only that the likelihood of a smolt surviving to adulthood was high, given the time and site of release. Hence, a comparative study of survival rate patterns can yield information about the effects of climate shifts and habitat quality.

2.4 Climate and Habitat Datasets

A broad exploratory analysis included a suite of variables describing the climate (sea surface temperature, upwelling, ENSO index, PDO index, plankton data from acoustic surveys), as well as the habitat (distance upstream, number of dams, river discharge, estuary area) that the CWT release groups were subject to. Scatterplots and GLM regression fits were used to select which habitat and climate predictor variables should be analyzed further, based on how well they fitted the survival rate patterns. The selected predictors are: sea surface temperature (SST) during the summer of the release year, distance upstream, and the number of dams.

It is still worthwhile to note the sources of data that ended up not being analyzed further, both because lack-of-fit results can be important on their own, and also because these predictors might be useful in another study, perhaps with a smaller geographical scope. The upwelling dataset was downloaded from the Pacific Fisheries Environmental Laboratory[1], the ENSO (El Niño Southern Oscillation) index from the NOAA Climate Prediction Center[2], and the PDO (Pacific Decadal Oscillation) index from the NOAA-CIRES Climate Diagnostics Center[3]. The plankton data were supplied by Dr. Gordon Swartzman at the University of Washington Applied Physics Laboratory, the river

1 http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/upwelling.html

2 http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/index.html

3 http://www.cdc.noaa.gov/Correlation/details.html

discharge datasets were downloaded from the U.S. Geological Survey website[4], and the estuary areas were primarily taken from Simenstad (1983). There are virtually endless ways to define predictor variables from these data, by using averages, medians, lower or upper bounds, variability, variable transformation, and so on, not to mention the choice of time frame. Clearly, it is not concluded here that the habitat and climate factors listed above do not affect salmon survival rates.

The SST data were supplied by Dr. Steven Hare at the International Pacific Halibut Commission in Seattle. His work is centered around oceanographic climate data and he has compiled surface temperature measurements and estimates from several sources to create a database with monthly averages at a resolution of 2° latitude by 2° longitude quadrats. Hatcheries were related to these quadrats by assigning each estuary to one quadrat (Figure 8). The time range of interest was defined as June–September, when the coho and chinook smolts are entering the estuaries and the ocean just outside the estuaries (Healey 1991, Sandercock 1991). Further fine tuning of this time matching was not attempted, since it would require an estimation of the speed of smolt downstream migration, which is likely to differ between river systems. The SST values of the months June–September were averaged, in an attempt to capture both unusually warm and unusually cool summer temperatures (Figure 9 and Table 4).

The predictor variables upstream distance and number of dams are only defined for a subset of the data, being hatcheries in Columbia and Fraser basins (Appendix B).

4 http://water.usgs.gov/nwis/discharge

Information about hatchery locations and their distance upstream was for the most part supplied by Laurie Weitkamp at the U.S. National Marine Fisheries Service in Seattle and Brenda Adkins at the Canadian Department of Fisheries and Oceans in Vancouver, British Columbia, but some hatcheries had to be located using on-line resources and maps. When the release site is known to differ from the actual hatchery location, the release site is used. The location of large dams in the Columbia Basin that are crossed by CWT release groups is shown in Figure 7, along with their names.

2.5 Generalized Linear Model (GLM)

Once the survival rate of each CWT release group has been estimated, an attempt is made to explain the observed variation with habitat and climate predictor variables. This is done by employing a Poisson regression model which belongs to a class of models called generalized linear models (GLM). The application of the Poisson GLM to CWT data was developed by Green and Macdonald (1987), Cormack and Skalski (1992), and Pascual (1993). This model can be algebraically rearranged into three equivalent forms as demonstrated by Cormack and Skalski (1992), using actual recoveries, expanded recoveries, or survival rate as the dependent variable.

It is worthwhile to review the initial steps of the CWT analysis. First, tagged salmon heads were retrieved (actual recoveries) and then sample fractions used to estimate how many tagged fish were represented by these tags (expanded recoveries). These steps, as well as the last one, transformation to standard age (implied recoveries), contribute to statistical uncertainty, analyzed by de Libero (1986). A simple empirical approach to visualize this uncertainty is to look at the survival rate distribution of CWT groups released from the same hatchery in the same month. Since survival rate has a lower bound at zero, the residual distribution gets skewed upwards when the mean survival rates are <1%, but look more symmetrical as the mean survival rate increases (Figure 10). This can be explained by the underlying variable, actual recoveries, which represents counts with few occurrences and the residuals of such variables are typically Poisson distributed. The Poisson distribution is skewed at low values and then becomes increasingly symmetrical at higher values.

The regression model has a log link function and either an offset or weights, depending on which form of the model is used. When actual recoveries are used as the dependent variable, the regression model takes the form:[5]

$$\log(Actual_i) = \log(Tagged_i \times Fraction_i) + \boldsymbol{\beta}\mathbf{X}_i \qquad \text{(Eq. 4a)}$$

where $Actual_i$ are the actual recoveries of CWT group i, $Tagged_i$ is the number tagged, $Fraction_i$ equals $Actual_i / Implied_i$, and $\boldsymbol{\beta}\mathbf{X}_i$ is the linear predictor. For CWT groups where both $Actual_i$ and $Implied_i$ equal zero (no recoveries occurred), $Fraction_i$ was set as the average value of *Fraction* for comparable CWT groups, released at the same hatchery in the same month for example. *Fraction* represents the sampling effort in a given area during the time of spawner return.

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5 In S-PLUS: glm(Actual~offset(Tagged*Fraction)+X, family=poisson(link=log))

The offset ($Tagged_i \times Fraction_i$) component becomes the weight when survival rate is used as the dependent variable:[6]

$$\log Survival_i = \boldsymbol{\beta}\mathbf{X}_i \qquad \text{(Eq. 4b)}$$

The regression model can be fitted using either Equation 4a or 4b, and the estimated values of **β** will be the same. The reasoning behind assuming Poisson error distribution is clear from Equation 4a, but the relationship between survival rate and the **β** parameters is best explained with Equation 4b. The objective of the iterative estimation algorithm is to find the estimates of **β** which minimize the deviance:

$$D = 2\sum_{i=1}^{n} w_i \left[y_i \log(y_i / \mu_i) - (y_i - \mu_i) \right] \qquad \text{(Eq. 5)}$$

where y_i is the observed value (survival rate, in the case of Eq. 4b) of CWT group i, μ_i is the fitted value, and w_i are the weights ($Tagged_i \times Fraction_i$ in the case of Eq. 4b). Deviance residuals r_D are defined such that $D = \sum_{i=1}^{n} r_{Di}^2$ and are calculated as:

$$r_{Di} = \text{sign}(y_i - \mu_i)\sqrt{2w_i \left[y_i \log(y_i / \mu_i) - (y_i - \mu_i) \right]} \qquad \text{(Eq. 6)}$$

where $\text{sign}(y_i - \mu_i)$ stands for a plus sign if $y_i \geq \mu_i$ but a minus sign for a negative residual (McCullagh and Nelder 1989, p. 39).

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6 In S-PLUS: glm(Survival~X, family=poisson(link=log), weights=(Tagged*Fraction))

As pointed out by Green and Macdonald (1987), the CWT data show strong overdispersion, meaning that the variance of actual recoveries is greater than the mean. To take this into account, they recommend using a scaled Poisson error distribution, which calls for a scale parameter φ, defined as:

$$\varphi = \frac{Var(Actual)}{E(Actual)} \qquad \text{(Eq. 7)}$$

The scale parameter does not affect the estimated values of the β regression coefficients but only the confidence limits around them, as $SE(\hat{\beta})$ becomes $\sqrt{\hat{\varphi}} \times SE(\hat{\beta})$. Once a model has been fitted, the scale parameter is estimated as the sum of squared working residuals, divided by the residual degrees of freedom (Venables and Ripley 1999, p. 217) and the scaled deviance is defined as $D/\hat{\varphi}$. This leads to the topic of model selection, which is covered in Section 4.1.

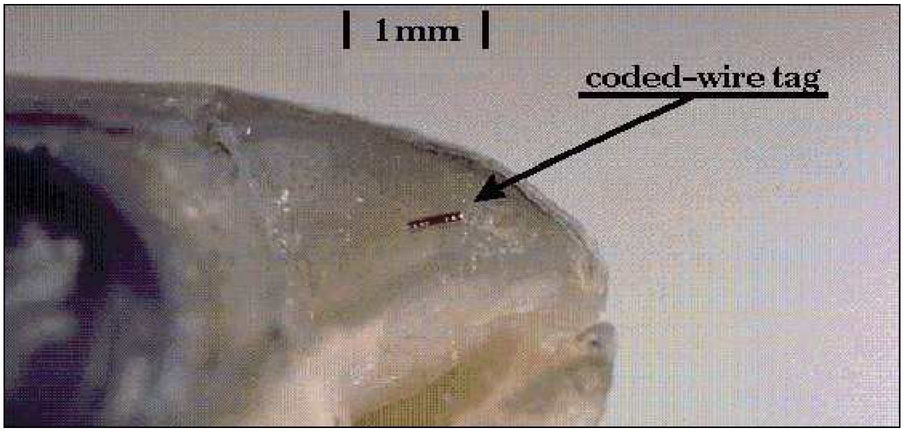

Figure 1 Snapshots from the tagging process and a close-up view of a tagged smolt snout. (Photographs courtesy of Lee Blankenship, WDFW)

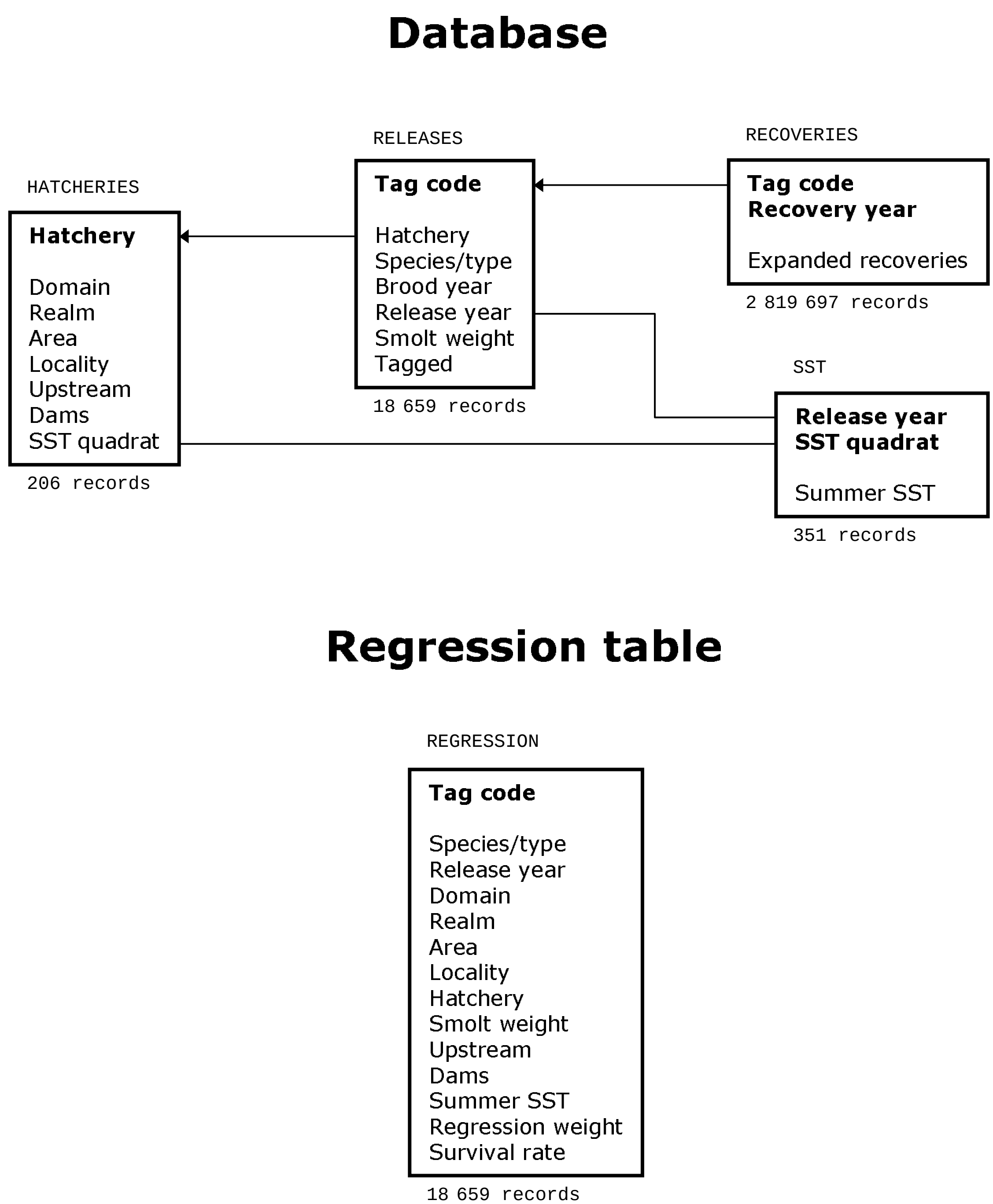

Figure 2 Database design, showing tables and their relationships. Fields in boldface represent the primary key of each table and arrows point at fields containing unique entries. The data are summarized in the regression table for analysis.

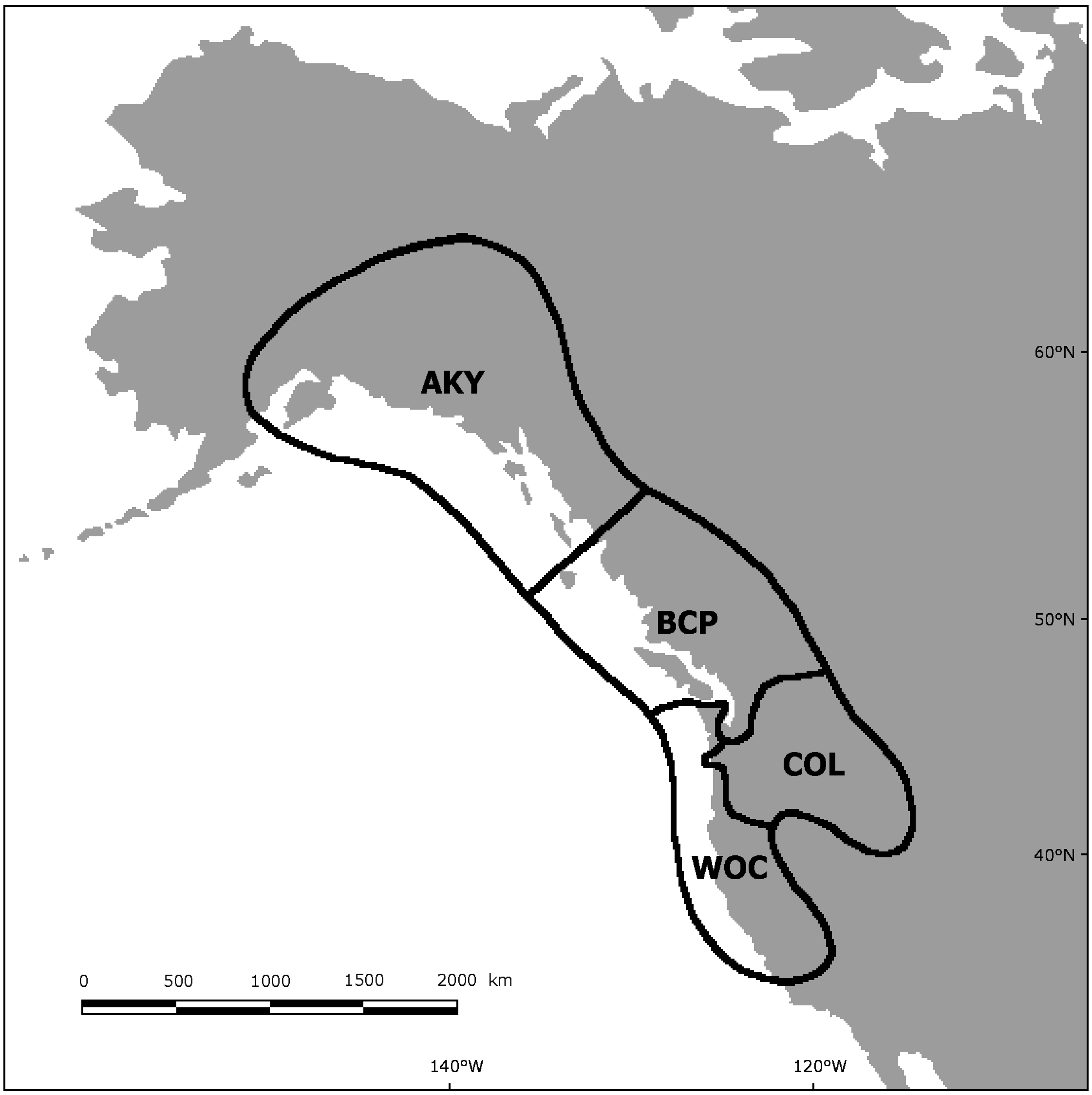

Figure 3 Map showing the extent of the four geographical domains. AKY = Alaska and Yukon, BCP = British Columbia and Puget Sound, WOC = Coastal Washington, Oregon and California, COL = Columbia Basin.

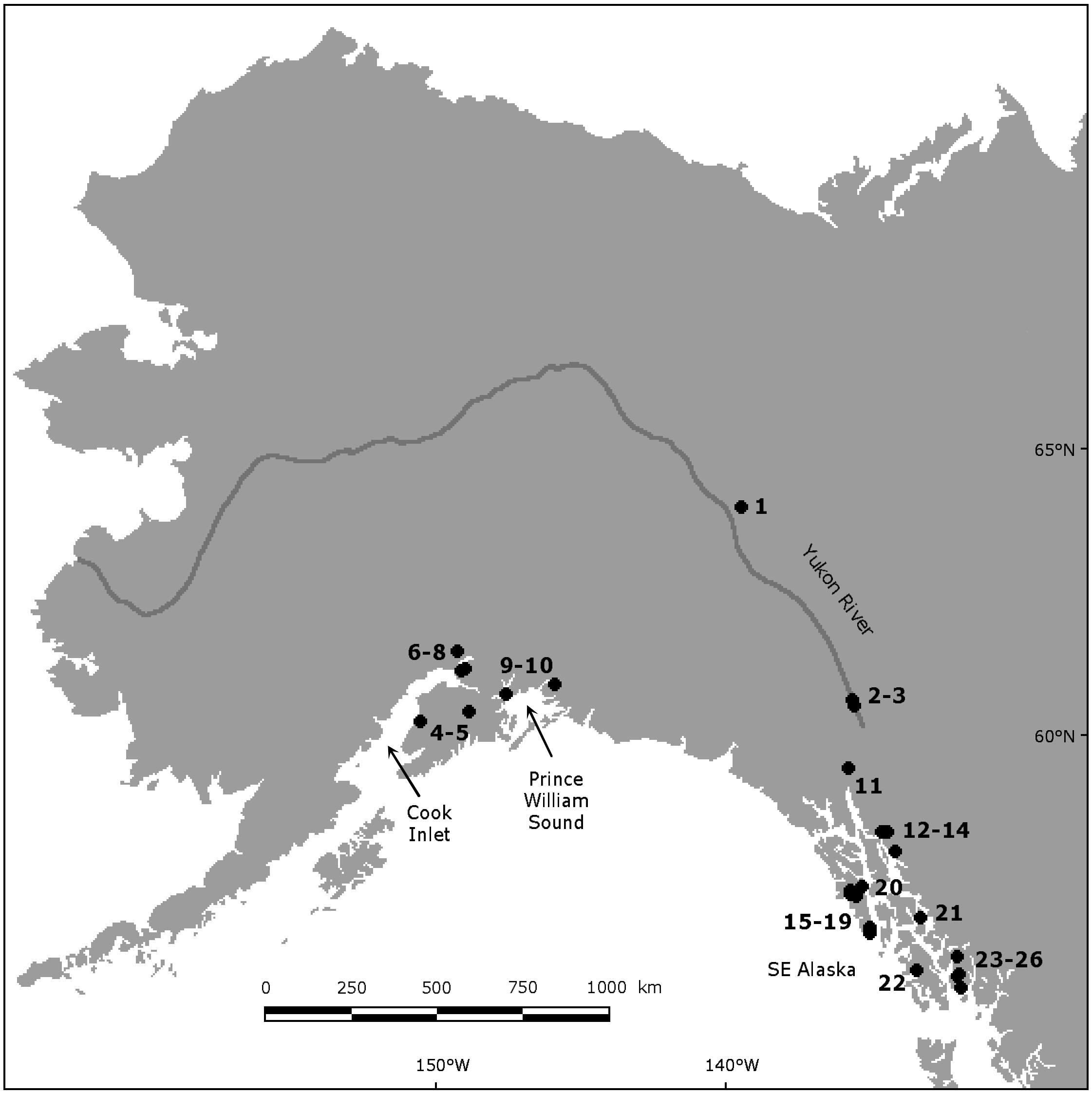

Figure 4 Map showing the 26 hatcheries located in Alaska and Yukon.

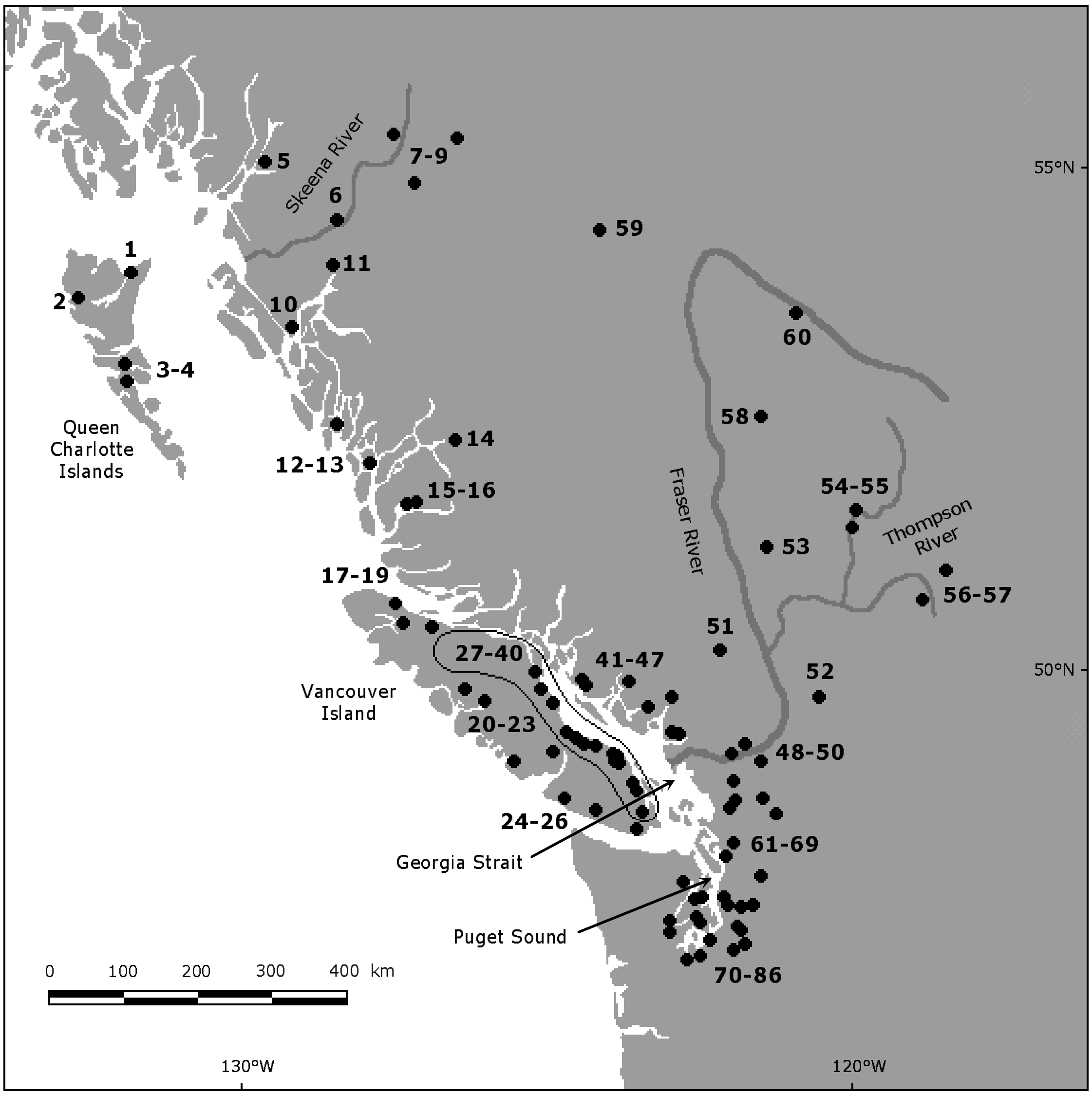

Figure 5 Map showing the 86 hatcheries located in British Columbia and Puget Sound.

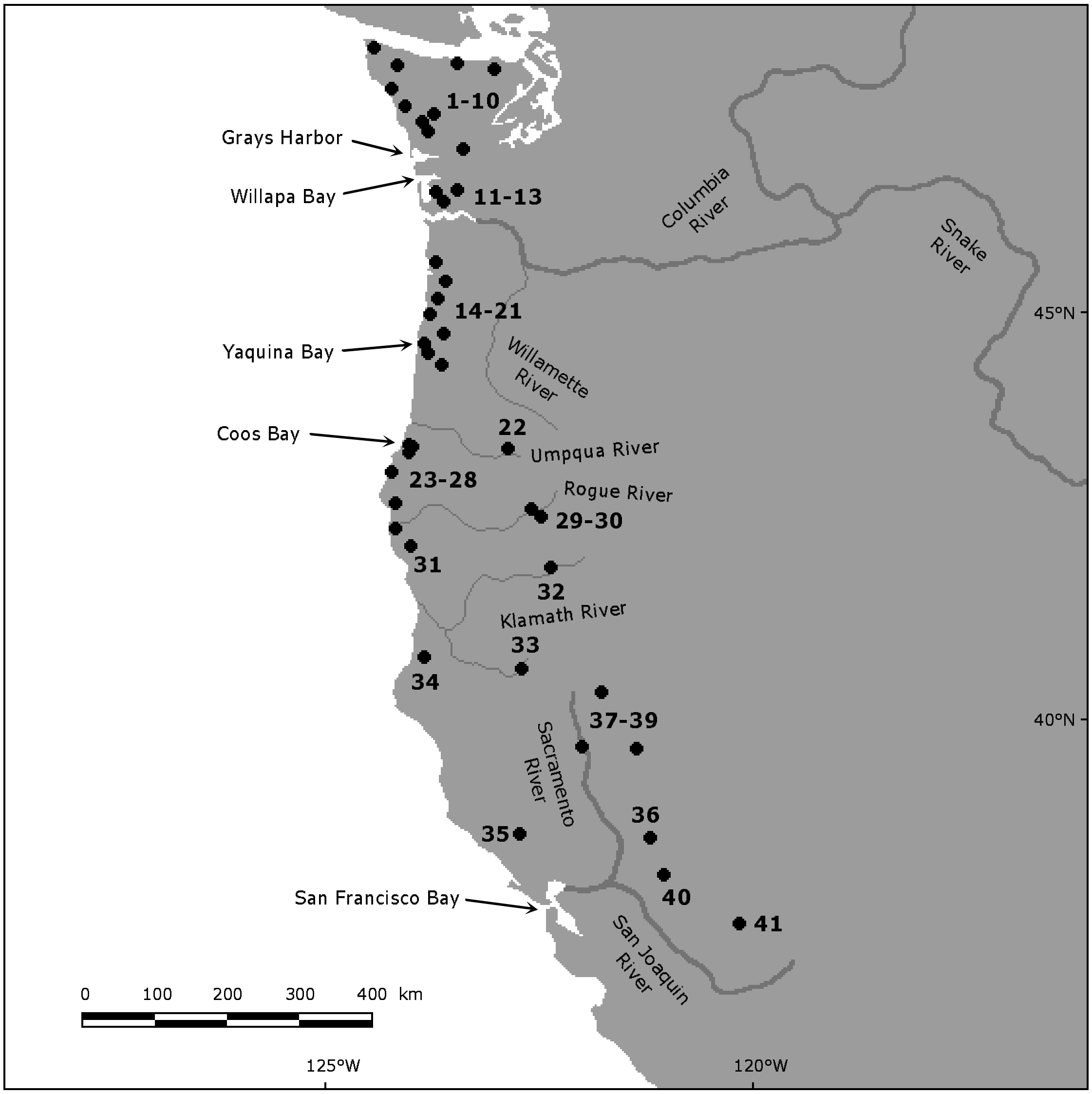

Figure 6 Map showing the 41 hatcheries located in coastal Washington, Oregon and California.

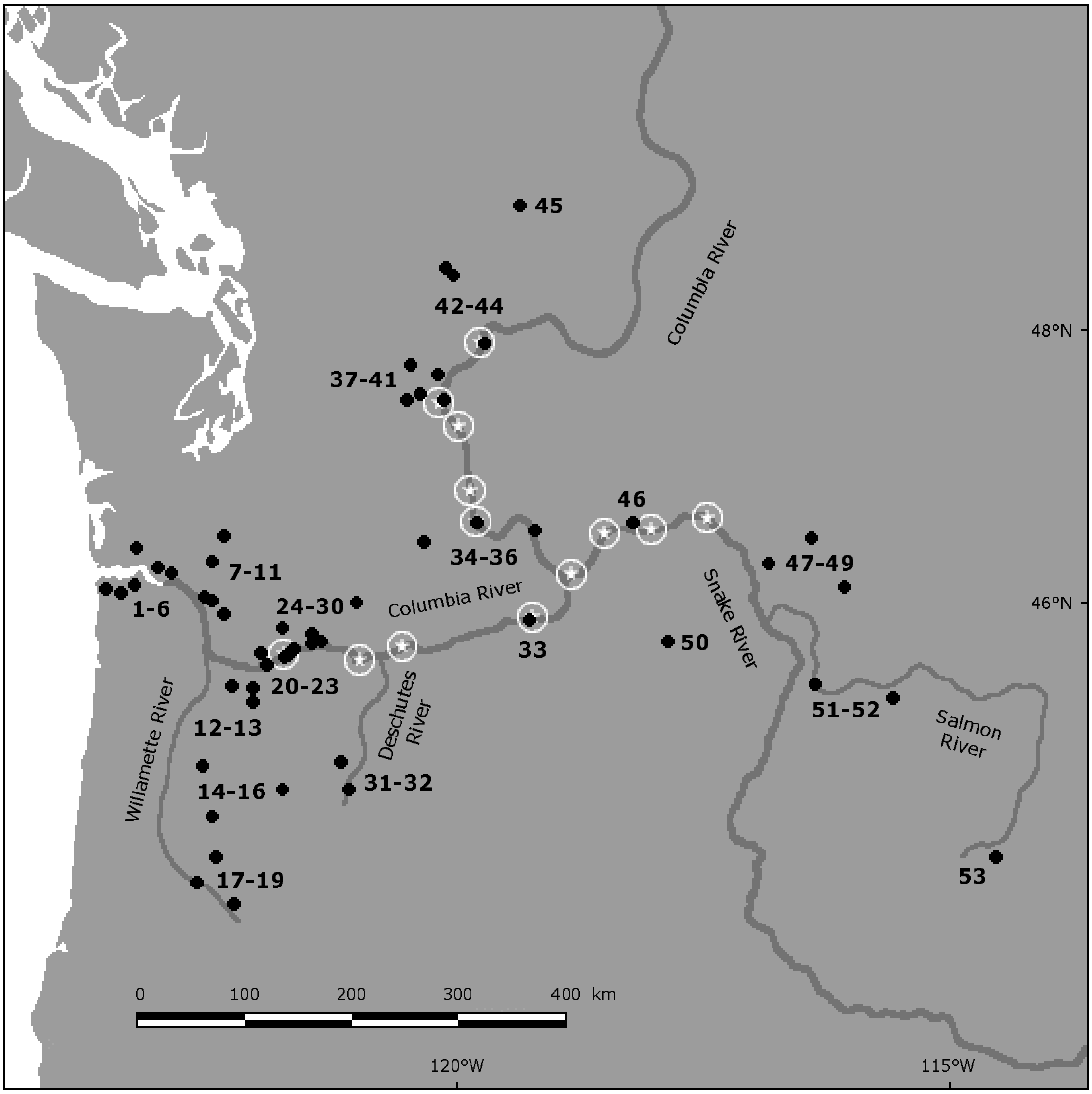

Figure 7 Map showing the 53 hatcheries located in Columbia Basin. White stars in circles show the location of dams. Starting from the river mouth, the dams in Columbia River are: Bonneville, The Dalles, John Day, McNary, Priest Rapids, Wanapum, Rock Island, Rocky Reach and Wells. In Snake River: Ice Harbor, Lower Monumental, Little Goose and Lower Granite.

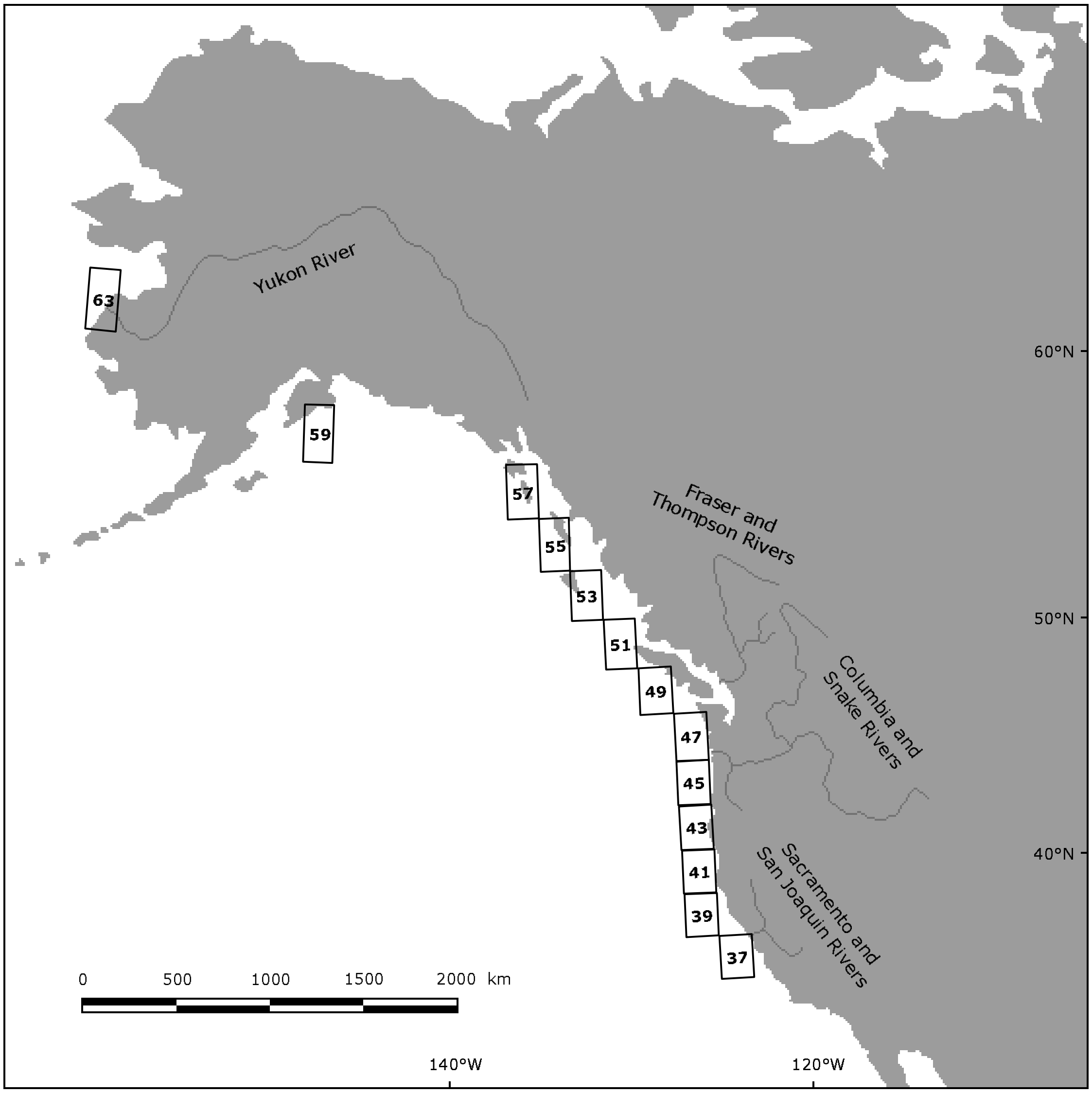

Figure 8 Map showing the 2° latitude by 2° longitude SST quadrats. These are used to relate summer sea surface temperature (SST) measurements to hatcheries, via the corresponding estuaries.

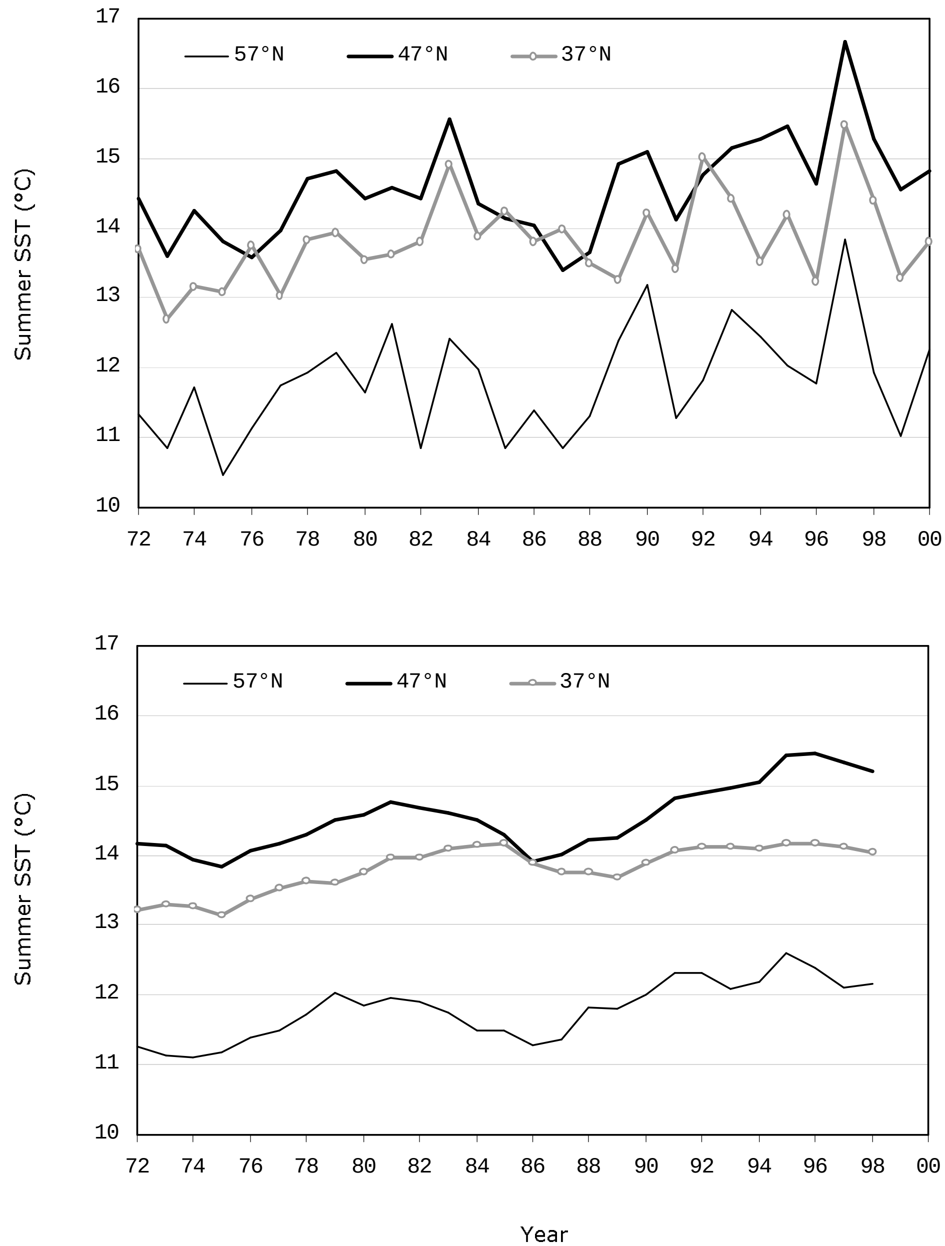

Figure 9 Summer sea surface temperature (SST) in quadrats 57°N, 47°N, and 37°N from 1972 to 2000. The upper graph shows the average temperature during June–September each year, and the lower graph shows the 5 year moving average of summer SST.

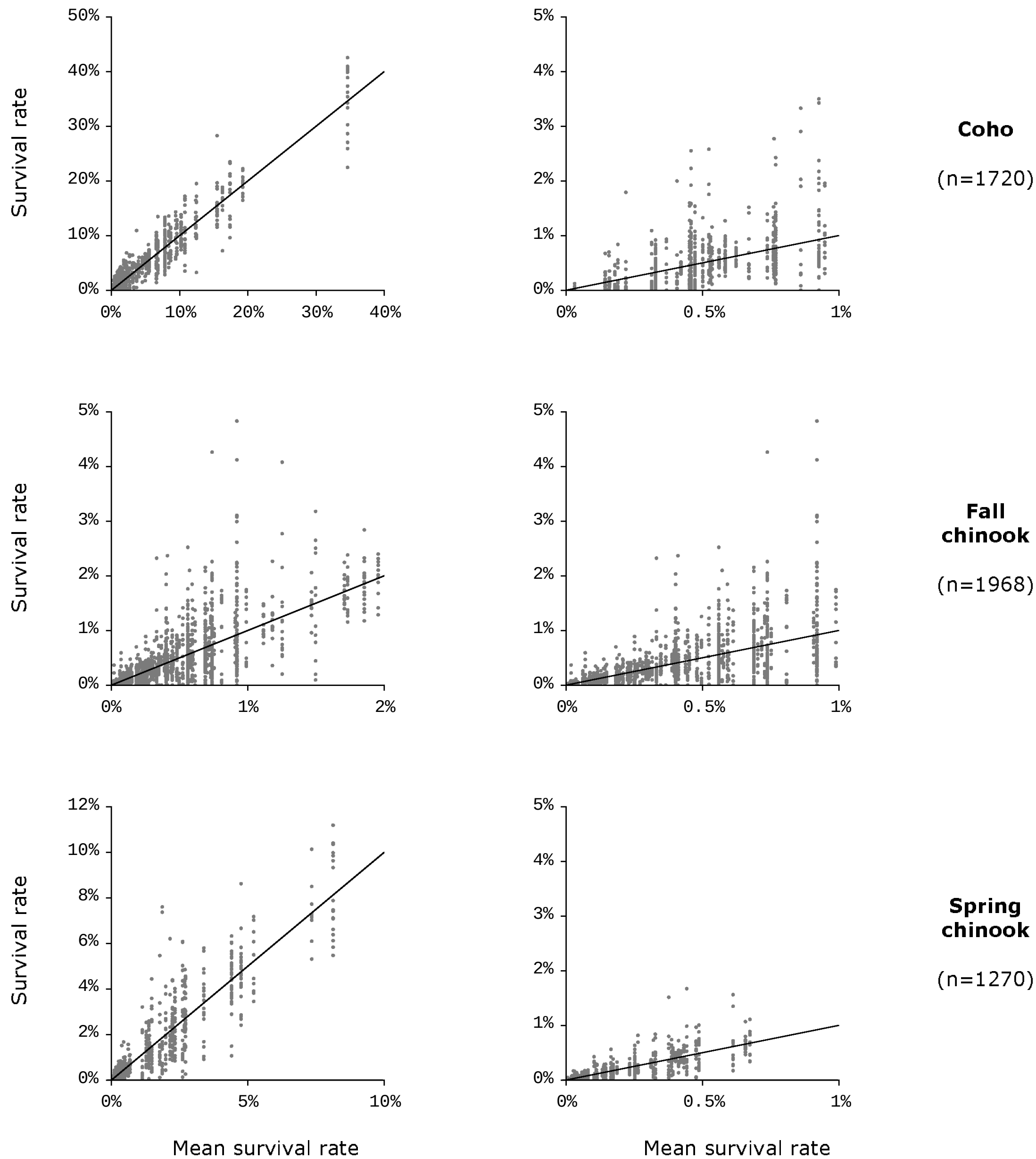

Figure 10 Survival rates of “replicated” CWT group releases. Each datapoint is the survival rate of a group where at least 10 groups of the same species were released from the same hatchery in the same month. These "replicates" are arranged on the X axis according to their mean survival rate. Graphs on the right zoom in on datapoints where the mean survival rate is less than 1%. The straight 1:1 line marks the mean survival rate.

Table 1 Age at recovery by species and type. The numbers show total expanded recoveries of CWT groups included in the study.

	Age							
	1	2	3	4	5	6	7	8
Coho	403	298 845	4 270 849	39 685	1 093	20		
	0%	6%	93%	1%	0%	0%		
Fall chinook	4 496	213 084	905 629	592 178	166 266	10 935	337	21
	0%	11%	48%	31%	9%	1%	0%	0%
Spring chinook	6	66 898	126 842	290 276	181 662	38 331	1 395	16
	0%	9%	18%	41%	26%	5%	0%	0%

Table 2 Summary of the 18 659 CWT release groups included in the study. Avg recovered stands for average expanded recoveries.

	CWT groups	Hatcheries	Release years	Median age at release	Median age at recovery	Avg tagged	Avg recovered
Coho	7279	128	1972–1998	2	3	19449	633
Fall chinook	7857	126	1972–1996	1	3	40837	241
Spring chinook	3523	69	1973–1996	2	4	32194	200

Table 3 Natural mortality rates used to standardize recoveries.

	Age							
	1	2	3	4	5	6	7	8
Coho	0.5	0.5	0.5	0.5	0.5	0.5		
Fall chinook	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1
Spring chinook	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1

Table 4 Summer sea surface temperature (°C) in each quadrat from 1972 to 2000.

	Quadrat												
Year	37	39	41	43	45	47	49	51	53	55	57	59	63
1972	13.7	14.0	13.4	14.0	14.8	14.4	13.5	12.9	12.6	11.7	11.3	10.7	7.9
1973	12.7	13.4	12.8	13.4	14.1	13.6	12.8	12.4	12.0	11.2	10.8	10.4	8.7
1974	13.2	13.8	13.2	13.8	14.6	14.2	13.4	13.0	12.7	11.9	11.7	11.7	9.6
1975	13.1	13.3	12.9	13.6	14.2	13.8	12.8	12.1	11.4	11.0	10.5	10.1	7.8
1976	13.7	13.9	13.2	13.5	14.0	13.6	12.6	12.1	11.7	11.3	11.1	10.8	8.2
1977	13.0	13.5	13.0	13.5	14.4	14.0	13.2	12.8	12.6	11.9	11.7	11.5	9.0
1978	13.8	14.3	13.6	14.2	15.1	14.7	13.8	13.3	13.1	12.2	11.9	11.5	9.8
1979	13.9	14.2	13.5	14.0	15.0	14.8	14.2	13.7	13.4	12.4	12.2	11.9	9.3
1980	13.6	13.8	13.1	13.8	14.7	14.4	13.6	13.2	13.0	11.9	11.6	11.4	9.1
1981	13.6	13.8	13.2	13.9	15.0	14.6	13.7	13.2	13.0	12.6	12.6	12.4	9.9
1982	13.8	14.2	13.7	14.3	14.9	14.4	13.4	12.7	12.1	11.5	10.9	10.2	4.9
1983	14.9	15.1	14.5	15.2	15.6	15.6	14.4	13.7	12.6	12.8	12.4	12.2	6.8
1984	13.9	13.9	13.3	13.8	14.7	14.4	13.4	12.7	12.1	12.0	12.0	12.2	7.3
1985	14.2	14.2	13.3	13.9	14.8	14.1	12.9	12.6	12.2	11.3	10.8	10.6	8.2
1986	13.8	13.9	12.8	13.3	14.3	14.0	13.1	12.9	12.5	11.9	11.4	10.9	8.2
1987	14.0	13.8	12.9	13.2	13.8	13.4	13.0	12.7	12.4	11.5	10.9	11.0	7.7
1988	13.5	13.3	12.1	12.5	13.8	13.6	13.1	12.6	12.1	11.5	11.3	11.4	9.8
1989	13.3	13.9	13.1	14.0	15.2	14.9	14.3	13.8	13.9	12.6	12.4	11.7	9.5
1990	14.2	15.0	14.3	14.4	15.2	15.1	14.7	14.5	14.4	13.3	13.2	12.0	9.4
1991	13.4	13.4	12.8	13.3	14.1	14.1	13.6	13.2	12.9	11.9	11.3	10.7	10.7
1992	15.0	15.0	14.3	14.4	15.0	14.8	14.1	13.6	13.2	12.1	11.8	11.1	4.9
1993	14.4	14.7	14.3	14.8	15.2	15.2	14.5	13.8	13.4	12.8	12.8	12.2	9.6
1994	13.5	14.6	14.4	15.1	15.6	15.3	15.0	14.2	13.4	12.6	12.5	11.6	8.3
1995	14.2	15.0	14.5	15.2	15.8	15.5	15.0	14.2	13.5	12.5	12.0	11.1	9.2
1996	13.2	13.8	13.6	14.2	14.9	14.6	14.0	13.5	12.9	12.0	11.8	11.9	9.4
1997	15.5	16.1	16.0	16.7	17.2	16.7	15.9	15.0	14.2	13.9	13.8	13.2	9.9
1998	14.4	14.4	13.9	14.5	15.2	15.3	14.8	14.1	13.5	12.4	11.9	11.4	9.2
1999	13.3	13.7	13.5	14.1	14.8	14.5	13.6	12.7	12.0	11.1	11.0	11.0	4.6
2000	13.8	14.1	13.6	14.1	14.9	14.8	14.2	13.5	12.9	12.1	12.3	11.6	8.9

Notes:
The quadrat name is its central latitude, but their central longitude is as follows: 37 = 123°W, 39 through 47= 125°W, 49 = 127°W, 51 = 129°W, 53 = 131°W, 55 = 133°W, 57 = 135°W, 59 = 149°W, and 63 = 165°W.
There is no quadrat 61 defined since no salmon are released into an estuary of that latitude.

3 SURVIVAL RATES

3.1 Geographical Scales

In order to visualize spatial trends in the survival rate data, it is useful to aggregate the hatcheries into several subsets. This aggregation becomes particularly meaningful if the subsets represent entities with common physical and biological attributes, as proposed by Ware and McFarlane (1989) who divided the U.S. and Canadian Pacific coast into four fisheries production domains. Out of those, three include hatcheries releasing coho and chinook salmon: the Central Subarctic Domain (Alaska), the Transitional Domain (British Columbia north of Vancouver Island), and the Coastal Domain (Vancouver Island and southward).

Another approach is to use the observed survival rate patterns themselves in a cluster analysis, as was done by Coronado and Hilborn (1998). From the coho CWT data, they found four hatchery clusters: A (lower Columbia River and coastal Oregon), B (subset of Puget Sound), C (subset of Georgia Strait and subset of Puget Sound), and D (Alaska and subset of Georgia Strait). Hobday and Boehlert (2001) also used coho CWT data, but yielded a different pattern of three clusters: 1 (Alaska and British Columbia north of Vancouver Island), 2 (Georgia Strait and Puget Sound), and 3 (west coast of Vancouver Island and southward).

In the study presented here, it soon became apparent that although coarse-scale geographical entities are useful to give a broad overview, there are important patterns that only emerge at intermediate geographical scales, with finer resolution than domains or clusters, but still grouping together a substantial number of hatcheries. Hence, geographical entities were defined at four different scales and called domains, realms, areas, and localities. Cluster analysis has the important merit of being a relatively objective approach, but there are still some subjective decisions about data manipulation and algorithm implementation. The example with the two cluster analyses mentioned above shows that different clusters can be yielded from similar data.

The approach adopted here could be described as ad-hoc bottom-up grouping, based on observed survival rates. First, a few neighboring hatcheries (3 on the average) were grouped together, paying special attention to river pathways. Then, the patterns in the survival rate time series of each locality was compared with that of close-by localities and these grouped together into areas, then realms, and finally domains (Table 5). In the following overview of spatial and temporal survival rate patterns of each species/type, references are made to domains, realms and areas, but patterns at the finest scales have been left out.

When hatchery releases are mentioned in the overview, they are measured in CWT groups and not in number of smolts, since the main purpose is to describe the amount of available survival rate data. The average number of smolts in a CWT group is around 160 000 for coho, 340 000 for fall chinook, and 100 000 for spring chinook.

3.2 Coho

Coho CWT groups have been released in all areas apart from Yukon River, Snake River, and San Francisco Bay. Releases are especially common in Georgia Strait, Columbia below dams, coastal Oregon, and SE Alaska (Figure 11). The intensity of CWT releases has generally been steady or increasing slightly (Figure 12), with the exception of coastal Oregon where the annual releases have fallen from over 100 in the 1980s down to around 20 groups in the 1990s.

The average survival rate of all 7279 CWT groups is 3.4%. The highest, 7.1%, is found in Puget Sound, 6.4% in Georgia Strait, and 4.8% in SE Alaska, while the lowest averages are 0.7% in W Alaska, and 0.8% both in N Oregon coast and N California coast (Figure 13). These patterns are far from being consistent in time, as Figure 14 shows. The average survival rates in British Columbia and Puget Sound have declined steadily from around 11% in the mid 1970s down to around 2% in the mid 1990s. During the same time period, the survival rates in Alaska have been increasing from around 1% to around 6%, except for low survival rates in 1986–1988. The survival rate patterns in Columbia Basin are characterized by large fluctuations (between 1.3% and 5.6%) during the 1980s, followed by very low survival rates in the 1990s, around 0.5%.

3.3 Fall Chinook

Fall chinook CWT groups have been released in all areas south of Alaska, in particular from hatcheries in the Columbia River (Figure 15). Fall chinook are also commonly released in areas surrounding Georgia Strait, San Francisco Bay, and S Oregon coast. In general, fall chinook are released at more southerly latitudes than spring chinook and not as far upstream. The annual release rate increased in 1985 across all domains and stayed high for some years, but has been decreasing in British Columbia and Puget Sound lately, as well as in Columbia Basin (Figure 16).

The average survival rate of all 7857 CWT groups is 0.8%. The highest, 1.5%, is found in coastal Oregon and W Vancouver Island, and 1.0% for groups released into Puget Sound, while the lowest survival rates are 0.1% in Snake River, 0.3% in Columbia above dams, and 0.6% in areas around Georgia Strait (Figure 17). The temporal patterns (Figure 18) are somewhat similar to those found for coho, being a steady decline in British Columbia and Puget Sound, from around 3% in the mid 1970s down to around 0.5% in the mid 1990s. Another similarity is the consistent low trend in Columbia Basin during the later years, around 0.2% on average in the 1990s.

3.4 Spring Chinook

More than half of the spring chinook CWT groups are released in Columbia Basin and almost a third in SE Alaska, leaving only a few hundred groups released anywhere else (Figure 19). Spring chinook hatcheries are typically found at northerly latitudes and/or far upstream, the most extreme examples being Yukon Territory and Idaho, both located deep inland. The annual release rate multiplied in Columbia Basin from the mid 1980s to the mid 1990s (Figure 20), primarily due to new hatcheries starting operation in Columbia above dams.

The average survival rate of all 3523 CWT groups is 0.9%. The highest, 1.8%, is found in SE Alaska, 1.3% on the Olympic Peninsula, and 1.0% in Puget Sound. The average survival rate in Columbia below dams, 0.9%, is strikingly higher than the 0.1% in Yukon and Snake rivers, both far upstream, and 0.2% in W Alaska and Columbia above dams (Figure 21). The temporal patterns (Figure 22) show declining survival rates across all domains from the 1980s to the 1990s. This is especially noteworthy in the case of Alaska, where coho survival rates increased during this time. The Columbia Basin looks just as bad as with coho and fall chinook with respect to the mid 1990s, the average survival rate being 0.2%.

3.5 Wild Populations

After this overview, the question arises whether the observed spatial and temporal patterns apply only to survival rates of hatchery-reared salmon or if they can be extrapolated to some degree to wild populations. This important question is hard to answer, especially because tagging studies of wild smolts are scarce compared with the extensive and long-term effort in tagging hatchery-reared smolts.

As an exploratory comparison, all coho and chinook CWT data records marked as wild smolts were filtered and analyzed in the same way as described in Sections 2.2 and 2.3. The resulting dataset consisted of 587 wild coho CWT groups, 157 fall chinook, and 115 spring chinook. However, a meaningful comparison with hatchery CWT groups was only possible if nearby hatcheries were releasing groups of the same species/type in the same year.

The longest comparative time series found (Figure 23) shows remarkably similar survival rate patterns of wild and hatchery-reared CWT groups. The time series of wild coho in Clearwater River was created by pooling together six different tagging sites in the same river, and the same was done for two tagging sites of wild fall chinook in the Trinity River.

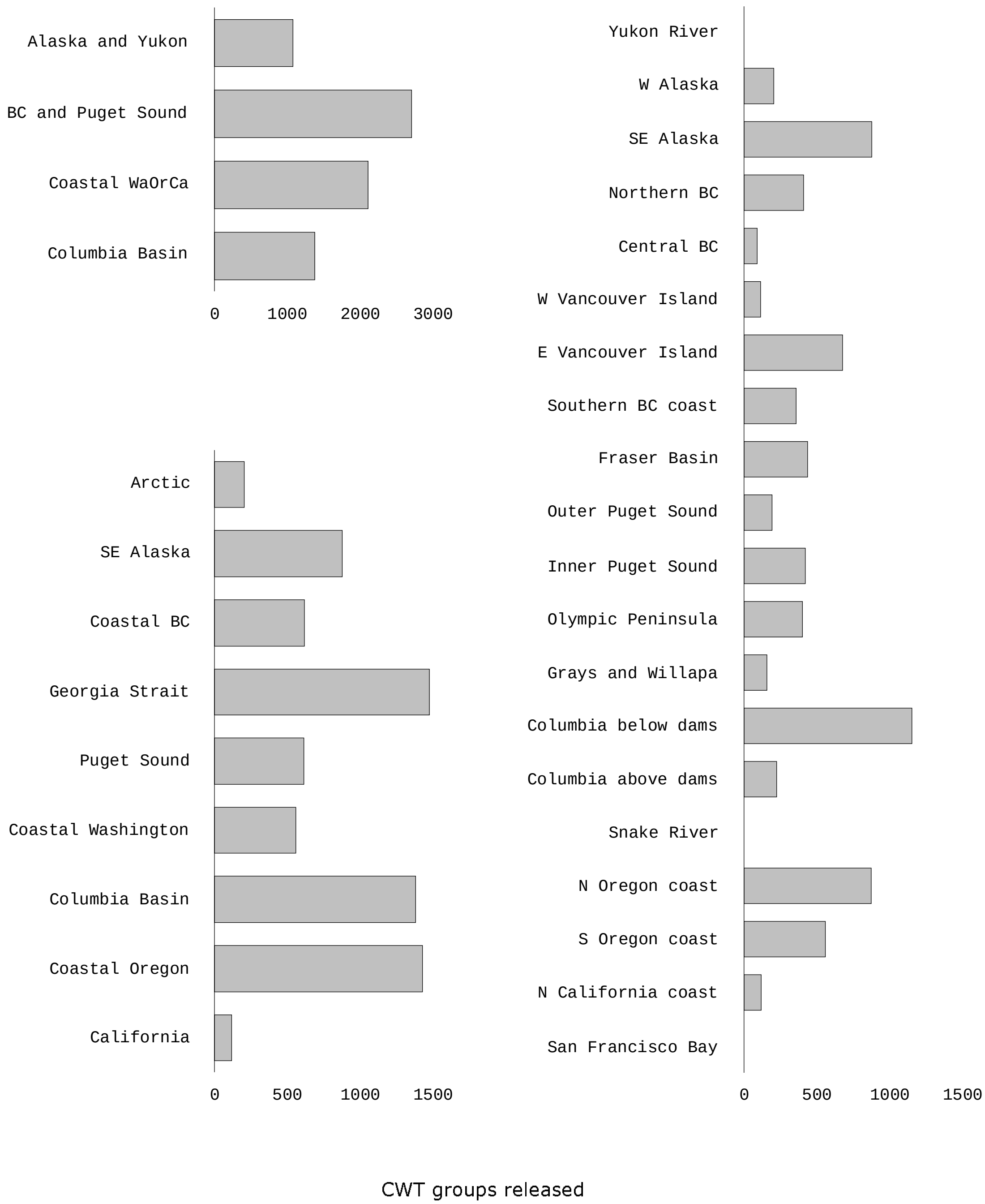

Figure 11 Coho CWT releases (n = 7279) stratified by geographical domains, realms, and areas. Empty spaces are used where no releases occurred.

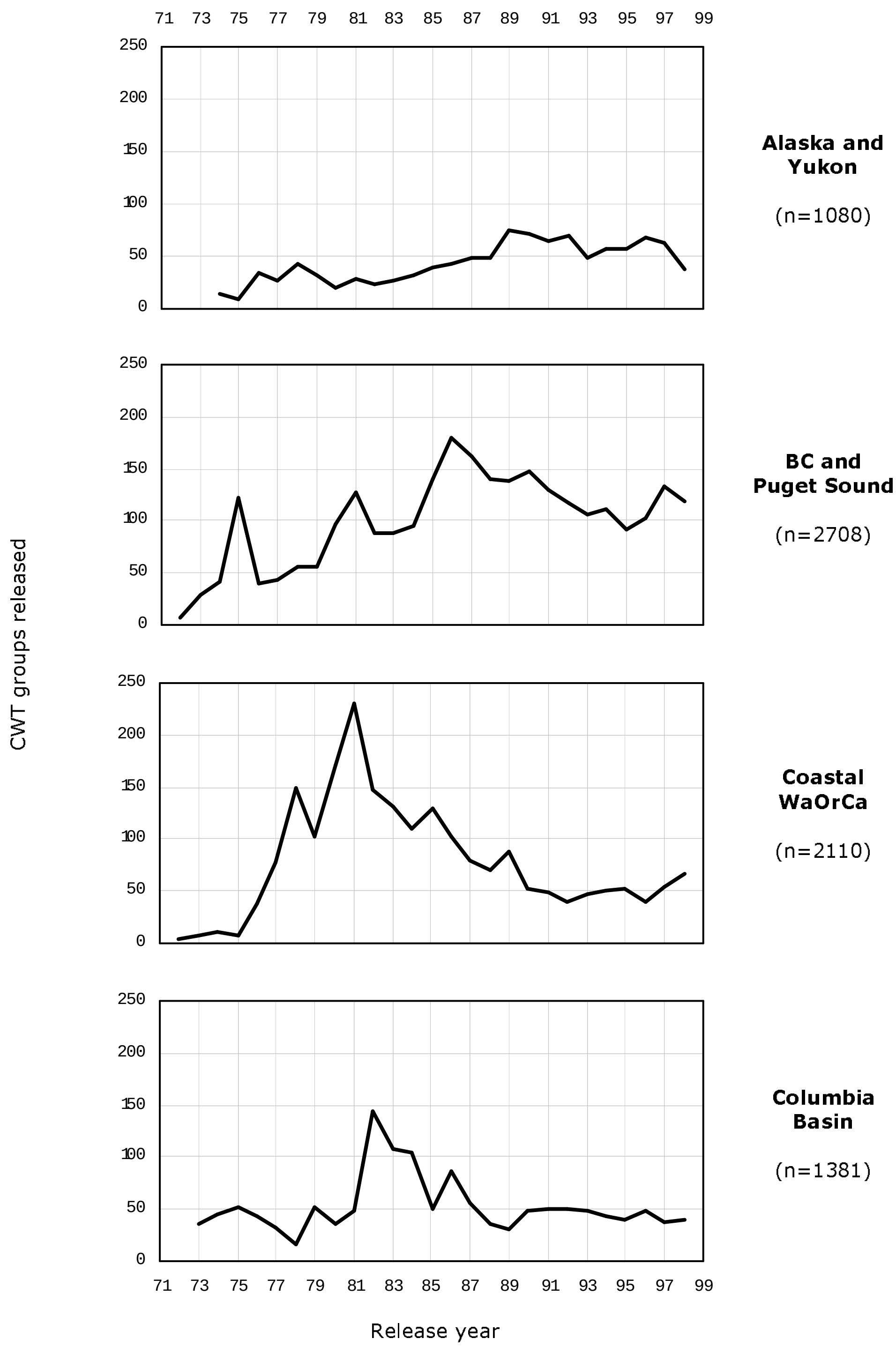

Figure 12 Coho CWT groups released per per year in each geographical domain.

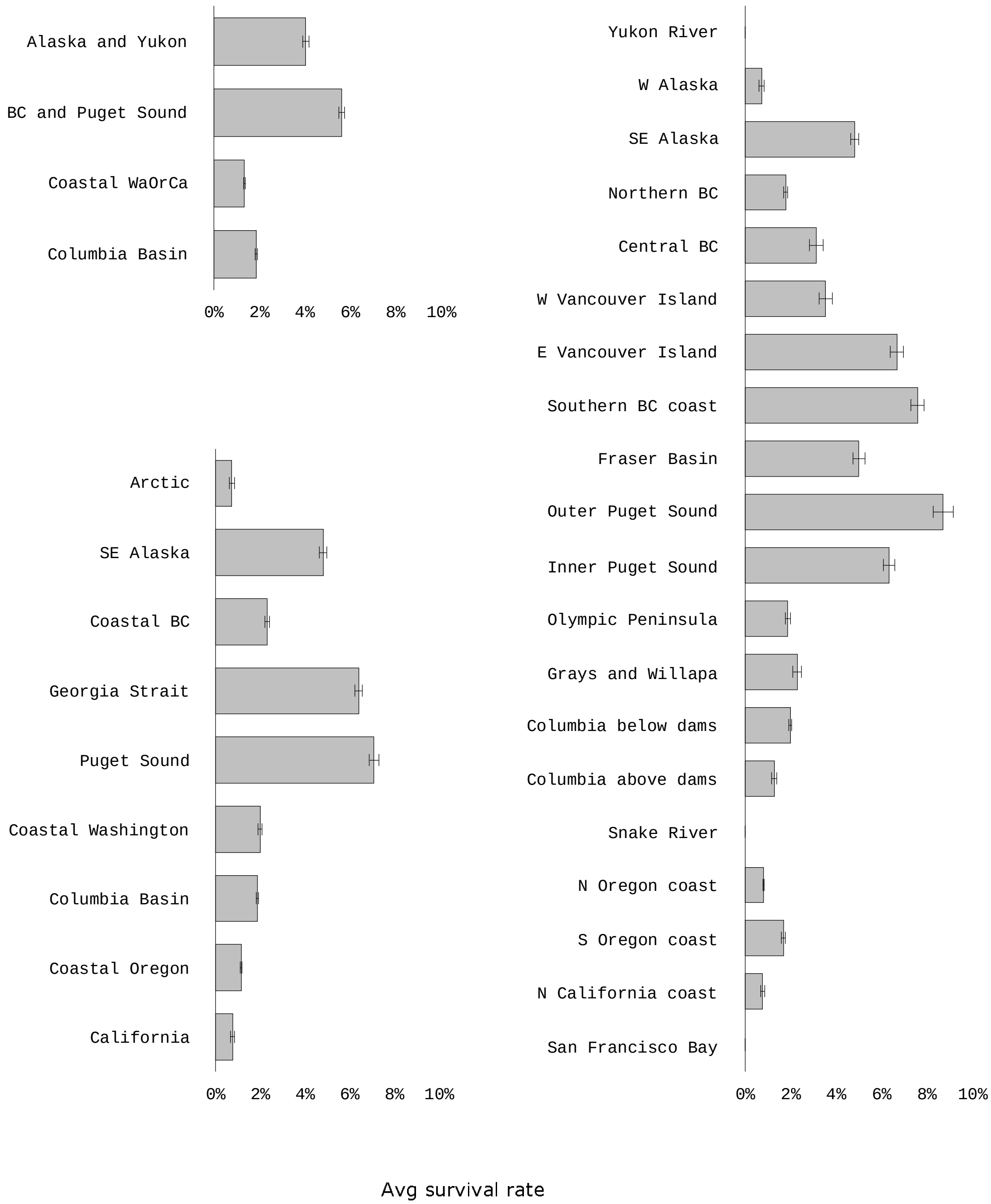

Figure 13 Coho survival rates stratified by geographical domains, realms, and areas. The error bars show the standard error of the mean, but empty spaces are used where no releases occurred.

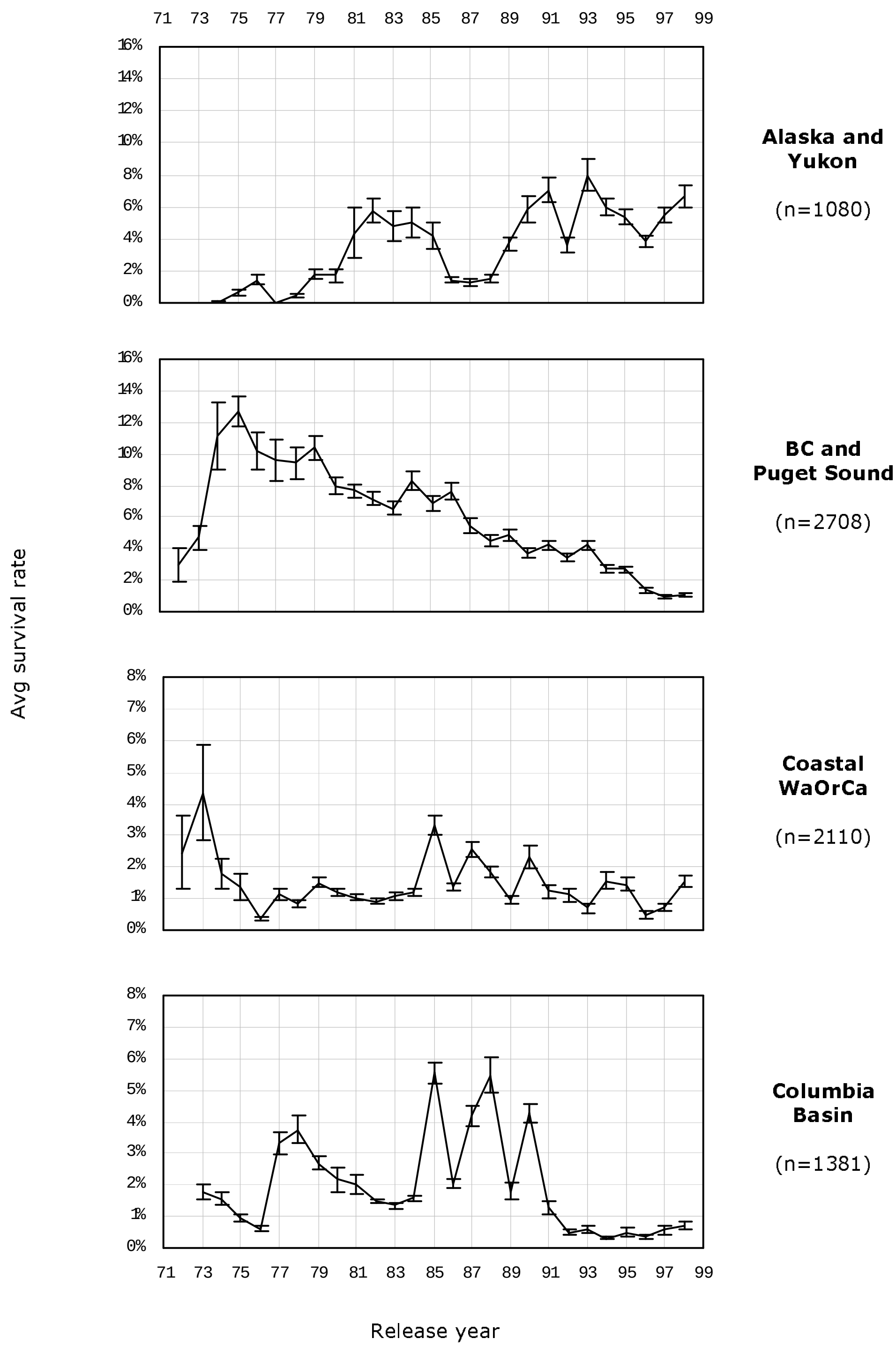

Figure 14 Coho survival rates by release year in each geographical domain. The error bars show the standard error of the mean. Note the different scales on the Y axis.

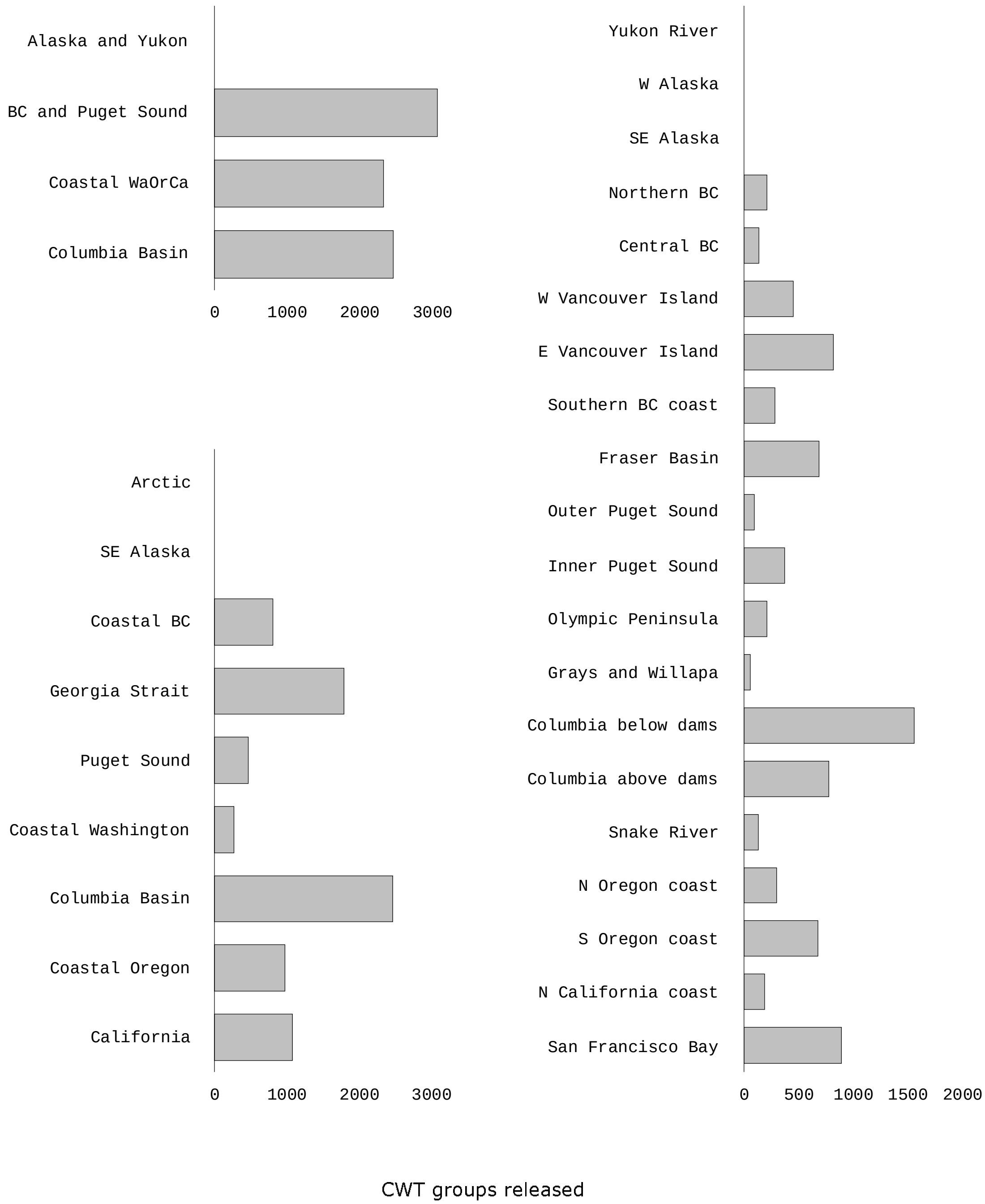

Figure 15 Fall chinook CWT releases (n = 7857) stratified by geographical domains, realms, and areas. Empty spaces are used where no releases occurred.

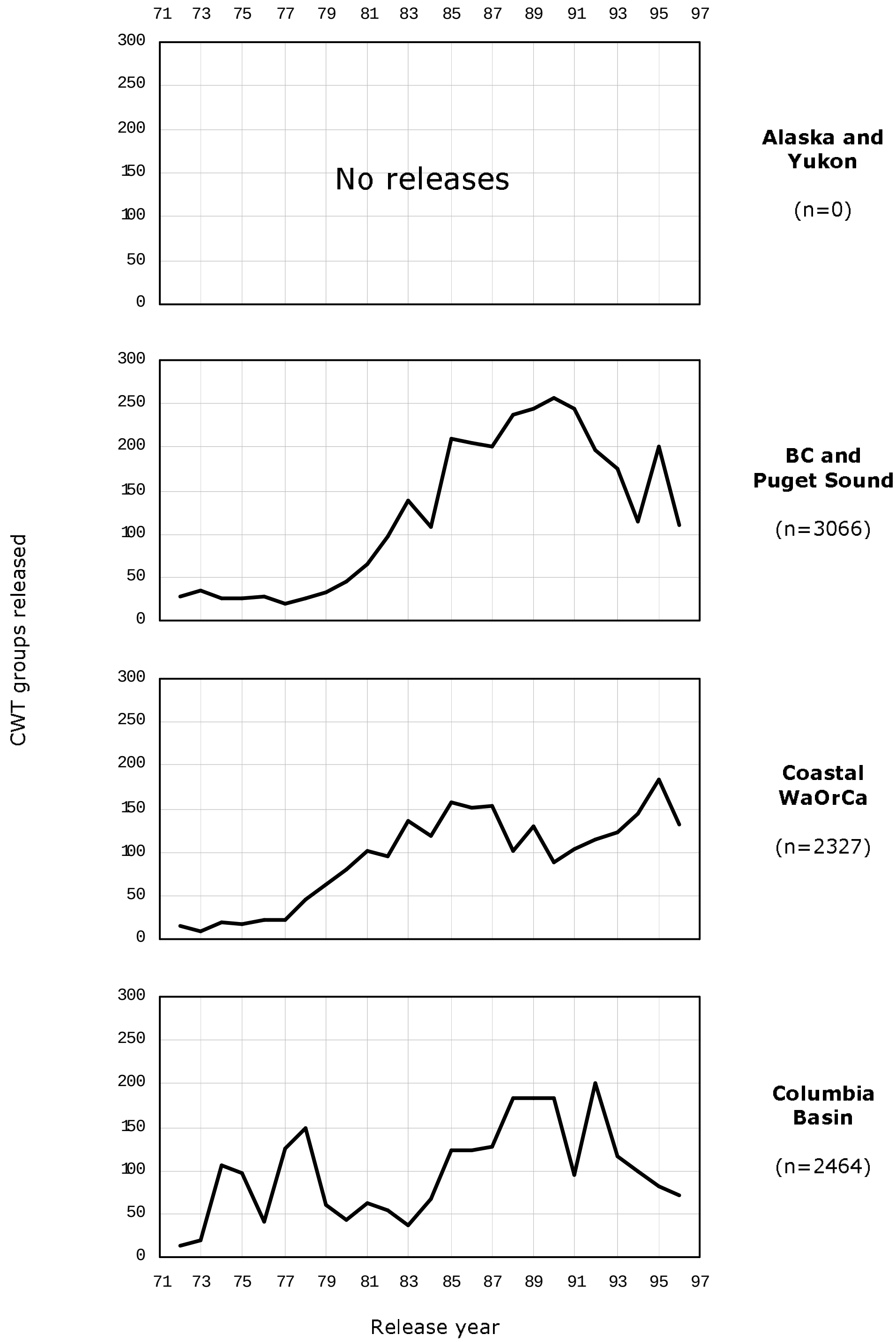

Figure 16 Fall chinook CWT groups released per year in each geographical domain.

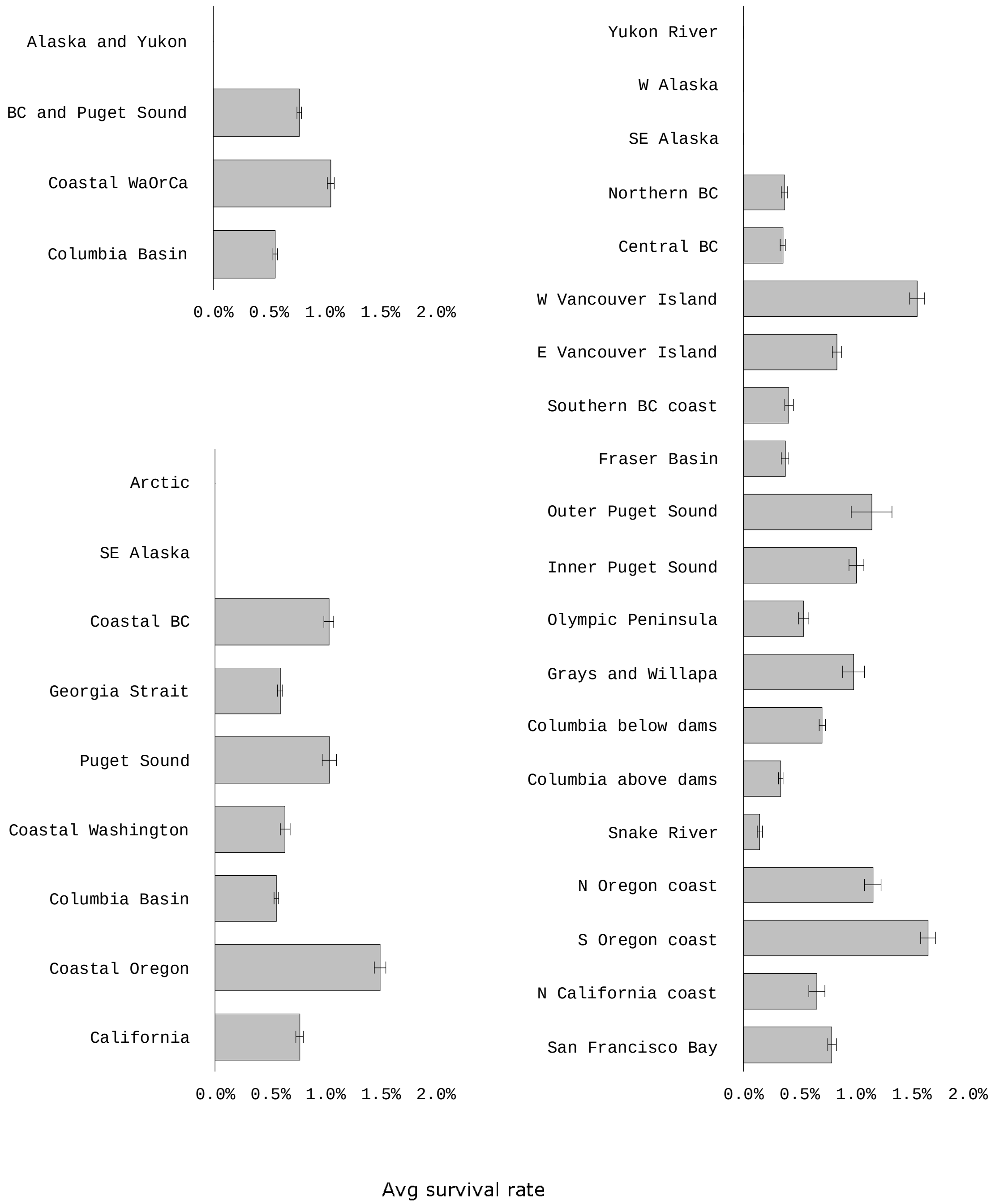

Figure 17 Fall chinook survival rates stratified by geographical domains, realms, and areas. The error bars show the standard error of the mean, but empty spaces are used where no releases occurred.

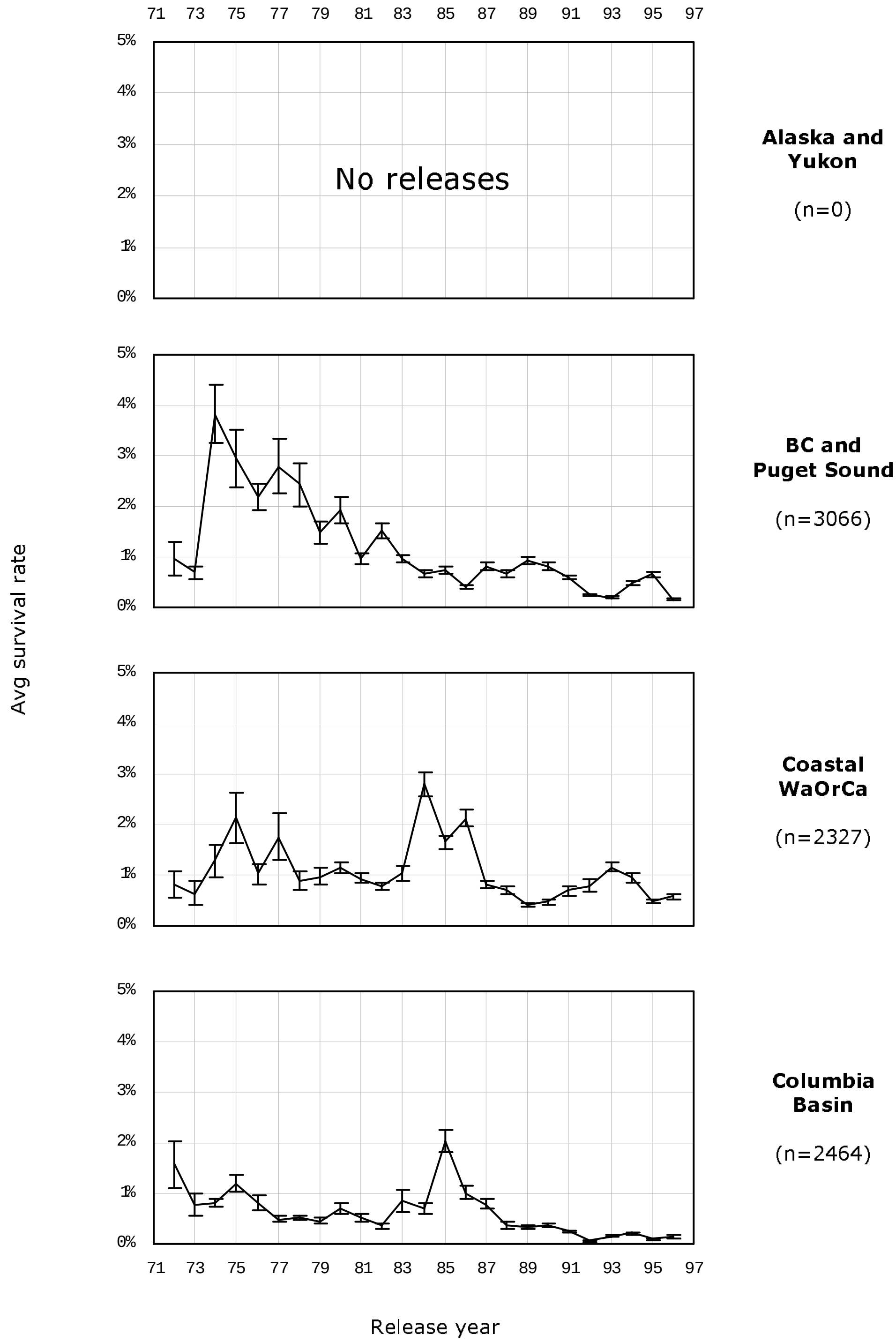

Figure 18 Fall chinook survival rates by release year in each geographical domain. The error bars show the standard error of the mean.

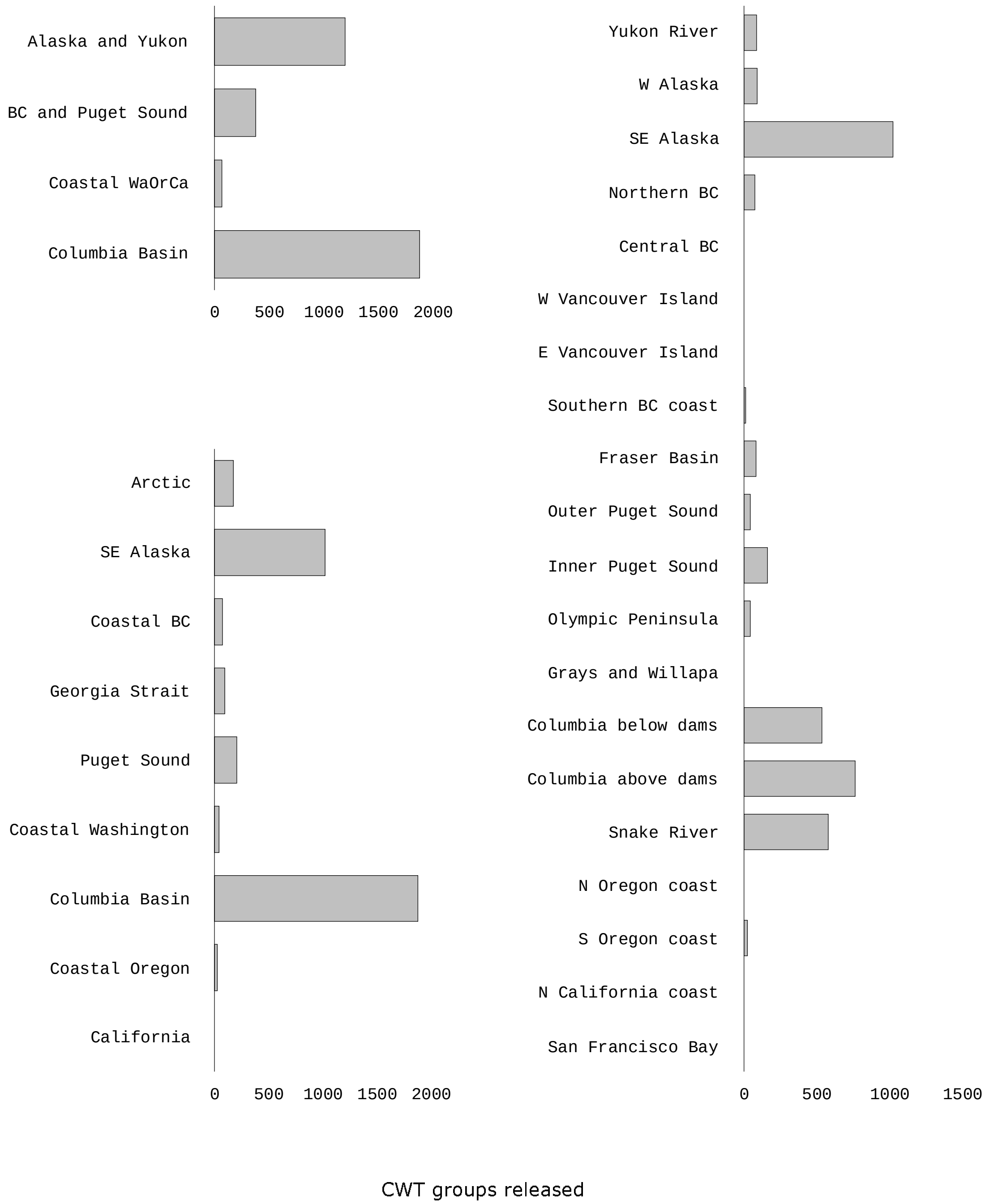

Figure 19 Spring chinook CWT releases (n = 3523) stratified by geographical domains, realms, and areas. Empty spaces are used where no releases occurred.

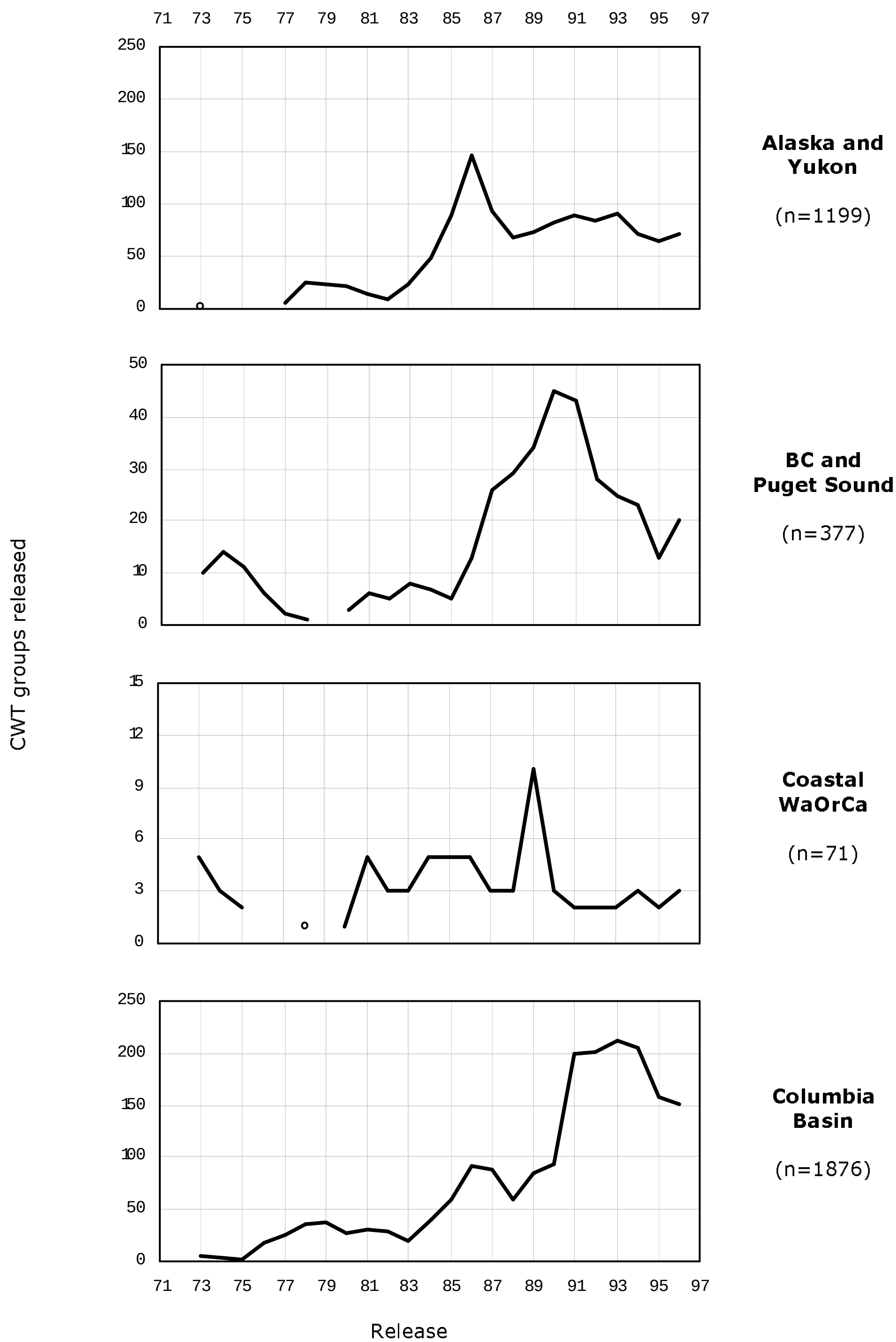

Figure 20 Spring chinook CWT groups released per year in each each geographical domain. Open circles are used for isolated line segments.

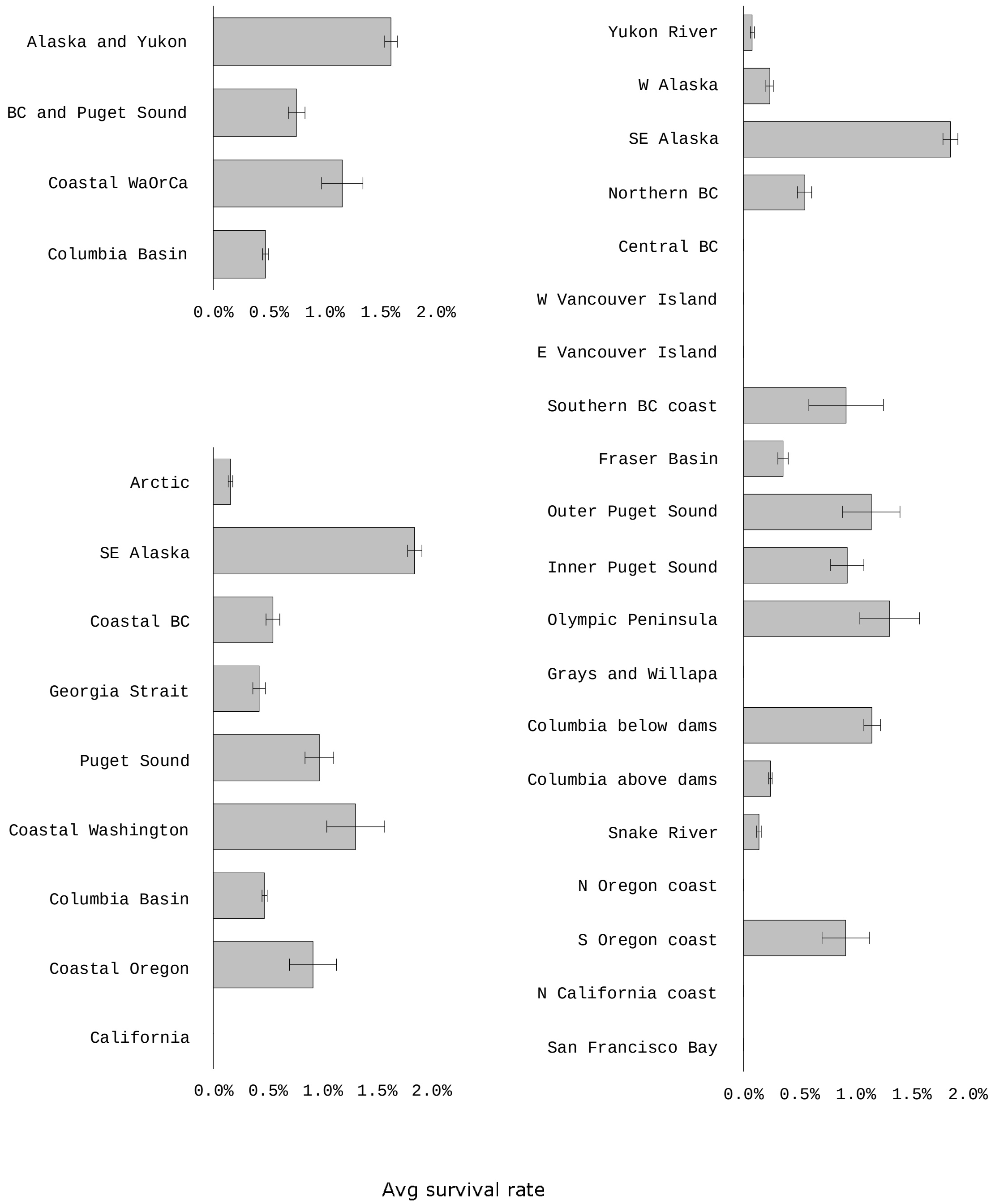

Figure 21 Spring chinook survival rates stratified by geographical domains, realms, and areas. The error bars show the standard error of the mean, but empty spaces are used where no releases occurred.

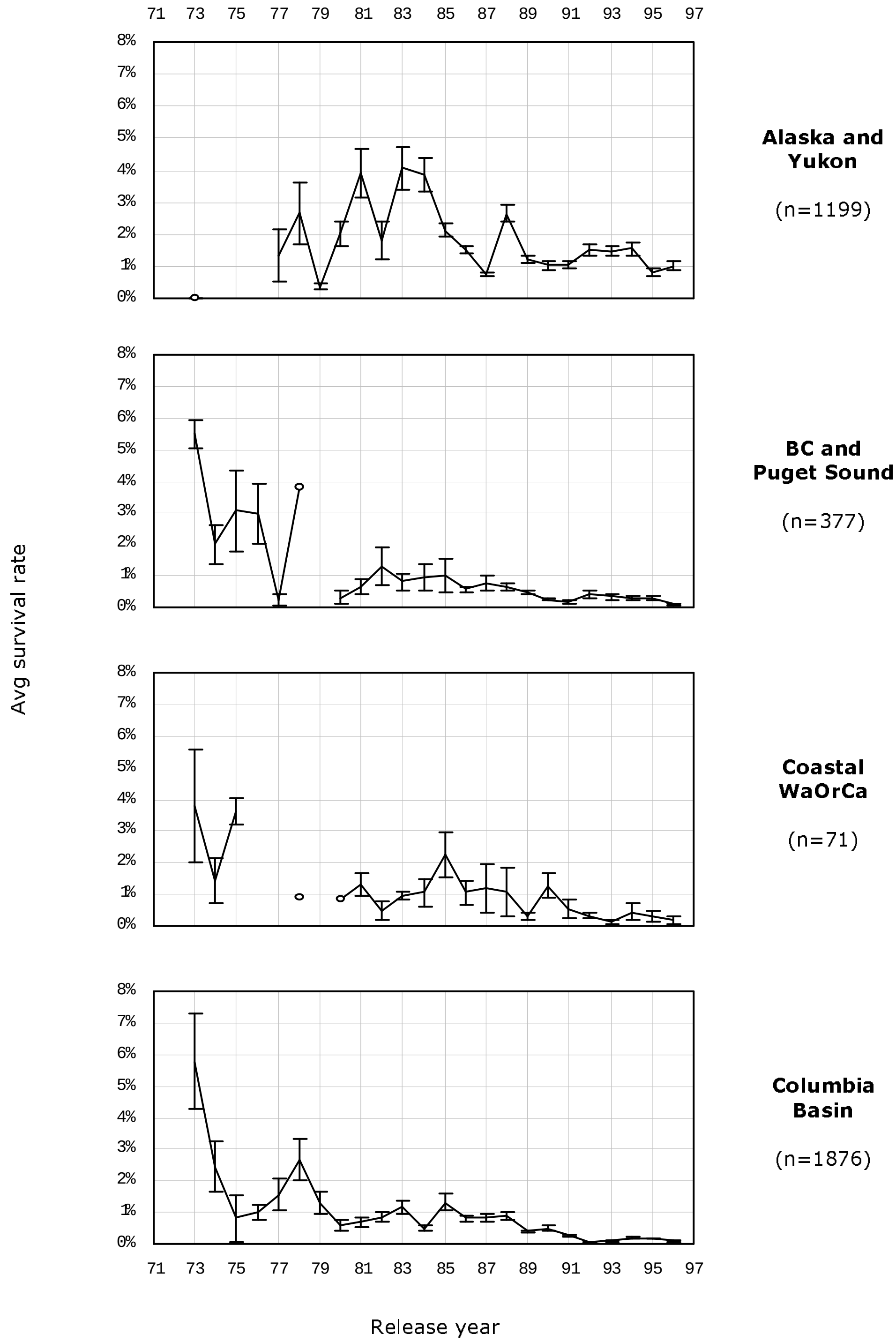

Figure 22 Spring chinook survival rates by release year in each geographical domain. The error bars show the standard error of the mean, but open circles are used when only one CWT group was released.

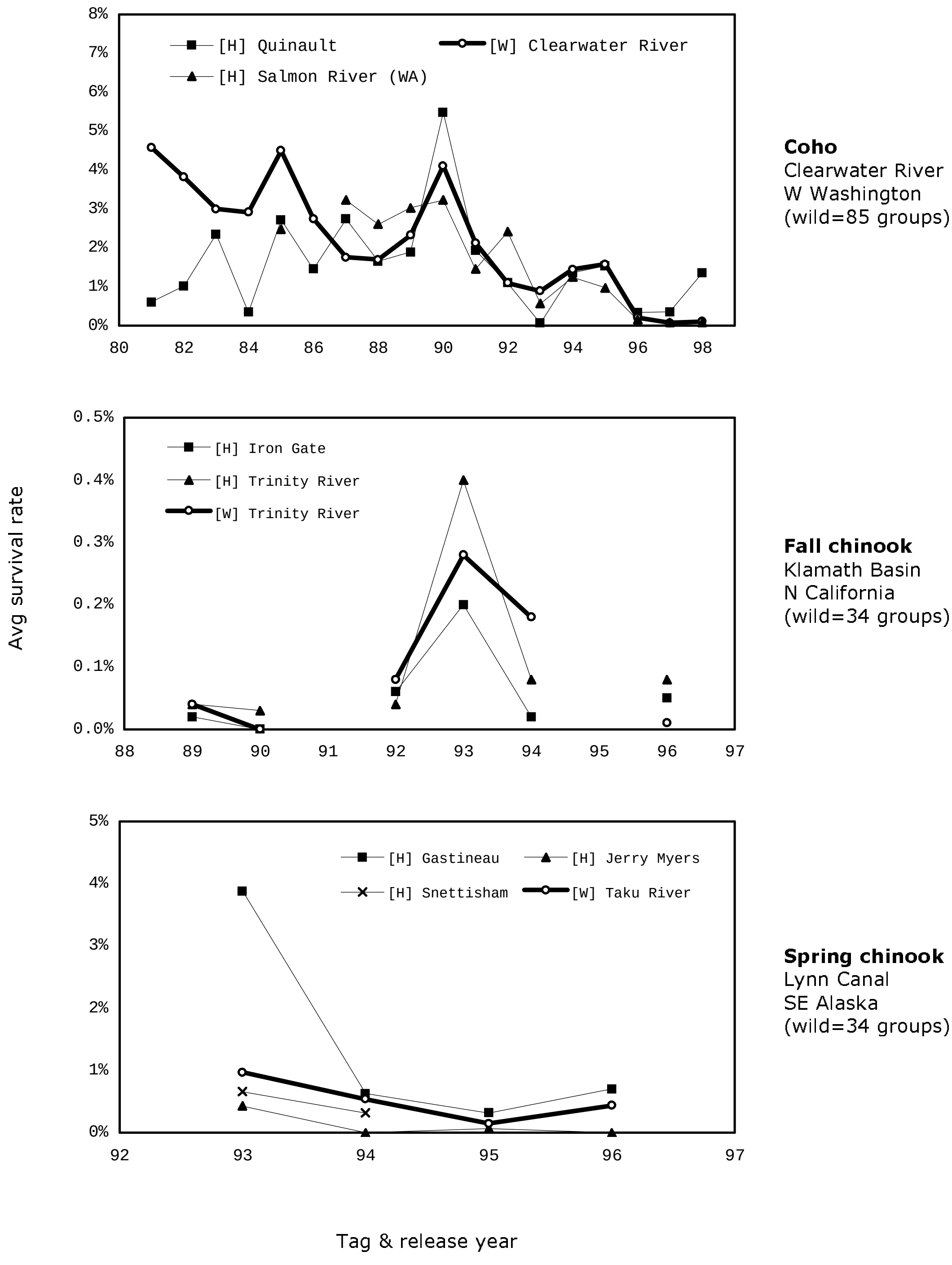

Figure 23 Average survival rates of tagged wild [W] smolts compared with those released from nearby hatcheries [H]. For the purposes of comparison, datapoints are only displayed in years when tagging was conducted both at hatcheries and in the wild.

Table 5 Relationship between domains, realms, areas, and localities. The fields C, F, and S show the number of hatcheries releasing coho, fall chinook and spring chinook, respectively.

Domain	Realm	Area	Locality	C	F	S
Alaska and Yukon	Subarctic	Yukon River	Yukon River			3
Alaska and Yukon	Subarctic	W Alaska	Cook Inlet	5		2
Alaska and Yukon	Subarctic	W Alaska	Pr William Sound	2		1
Alaska and Yukon	SE Alaska	SE Alaska	Lynn Canal	3		3
Alaska and Yukon	SE Alaska	SE Alaska	Baranof Island	6		4
Alaska and Yukon	SE Alaska	SE Alaska	Mitkof and Pr of Wales	2		1
Alaska and Yukon	SE Alaska	SE Alaska	Ketchikan area	4		4
BC and Puget Sound	Coastal BC	Northern BC	Qn Charlotte Islands	4	1	
BC and Puget Sound	Coastal BC	Northern BC	Nass and Skeena	5	1	4
BC and Puget Sound	Coastal BC	Northern BC	Douglas Channel	2	1	
BC and Puget Sound	Coastal BC	Central BC	Qn Charlotte Sound	4	4	
BC and Puget Sound	Coastal BC	W Vancouver Island	NW Vancouver Island	1	3	
BC and Puget Sound	Coastal BC	W Vancouver Island	SW Vancouver Island	3	5	
BC and Puget Sound	Georgia Strait	E Vancouver Island	E Vancouver Island	4	6	
BC and Puget Sound	Georgia Strait	E Vancouver Island	SE Vancouver Island	4	4	
BC and Puget Sound	Georgia Strait	Southern BC coast	Malaspina Strait	4	2	1
BC and Puget Sound	Georgia Strait	Southern BC coast	Burrard and Howe	2	3	
BC and Puget Sound	Georgia Strait	Fraser Basin	Lower Fraser	3	3	
BC and Puget Sound	Georgia Strait	Fraser Basin	Birkenhead River		1	
BC and Puget Sound	Georgia Strait	Fraser Basin	Thompson River	3	5	2
BC and Puget Sound	Georgia Strait	Fraser Basin	Upper Fraser		2	1
BC and Puget Sound	Puget Sound	Outer Puget Sound	NE Puget Sound	2	3	1
BC and Puget Sound	Puget Sound	Outer Puget Sound	E Puget Sound	5	2	1
BC and Puget Sound	Puget Sound	Inner Puget Sound	SE Puget Sound	6	5	
BC and Puget Sound	Puget Sound	Inner Puget Sound	S Puget Sound	3	4	3
BC and Puget Sound	Puget Sound	Inner Puget Sound	Hood Canal	2	3	2
Coastal WaOrCa	Coastal Washington	Olympic Peninsula	N Olympic Peninsula	3	2	1
Coastal WaOrCa	Coastal Washington	Olympic Peninsula	S Olympic Peninsula	5	4	1
Coastal WaOrCa	Coastal Washington	Grays and Willapa	Grays Harbor	2	2	
Coastal WaOrCa	Coastal Washington	Grays and Willapa	Willapa Bay	2	2	
Columbia basin	Columbia basin	Columbia below dams	Columbia mouth	5	5	
Columbia basin	Columbia basin	Columbia below dams	First Columbia tribs	5	5	2
Columbia basin	Columbia basin	Columbia below dams	Willamette River	1	7	7
Columbia basin	Columbia basin	Columbia below dams	Bonneville below dam	4	2	1
Columbia basin	Columbia basin	Columbia above dams	Mid Columbia	4	8	6
Columbia basin	Columbia basin	Columbia above dams	Upper Columbia		3	9
Columbia basin	Columbia basin	Snake River	Lower Snake		1	1
Columbia basin	Columbia basin	Snake River	Upper Snake		4	6
Coastal WaOrCa	Coastal Oregon	N Oregon coast	N Oregon coast	2	2	
Coastal WaOrCa	Coastal Oregon	N Oregon coast	Salmon and Siletz	2	1	
Coastal WaOrCa	Coastal Oregon	N Oregon coast	Yaquina Bay	2	1	
Coastal WaOrCa	Coastal Oregon	S Oregon coast	C Oregon coast	2	2	1
Coastal WaOrCa	Coastal Oregon	S Oregon coast	Coos Bay	3	2	1
Coastal WaOrCa	Coastal Oregon	S Oregon coast	S Oregon coast	3	6	
Coastal WaOrCa	California	N California coast	N California coast	4	3	
Coastal WaOrCa	California	San Francisco Bay	Sacramento River		4	
Coastal WaOrCa	California	San Francisco Bay	San Joaquin River		2	

Note: In the Domain field, “Coastal WaOrCa” is used as shorthand for Coastal Washington, Oregon, and California.

4 REGRESSION ANALYSIS

4.1 Model Selection

When selecting which predictor variables and interactions to incorporate in a regression model, decisions are commonly based on a predefined model comparison statistic, such as the Akaike information criterion (AIC) and its Bayesian counterpart, BIC. In the case of a model with an unknown scale parameter, Venables and Ripley (1999, p. 215) recommend using the statistic $\Delta D/(\hat{\varphi}\times\Delta p)$ where ΔD is the deviance gained by incorporating Δp more parameters. For significance tests, this statistic is approximately F distributed with Δp and $n-p_1$ degrees of freedom, where n is the total number of datapoints and p_1 is the number of parameters in the model being tested. With this criterion at hand, one could implement an automated selection algorithm — forward, backward, or stepwise — to end up with a model containing the most significant regression terms.

The approach taken in this study was not to include as many significant terms as possible, but to capture the major survival rate trends with very simple models, being considerably more strict than the F-test at the 0.05 significance level. Generally, this test served an auxiliary role, placing greater emphasis on residual patterns and predictor correlation.

4.2 SmoltWt Model

Judging from the literature, the relationship between smolt weight and survival rate is one of the most consistent trends documented, making it a sensible starting point for the regression analysis. The median smolt weight at release is around 23 g for coho, 7 g for fall chinook, and 28 g for spring chinook, owing to the fact that fall chinook smolts are one year younger than coho and spring chinook at the time of release.

Smolt weight was used log-transformed[7] in the regression, since this resulted in improved deviance, and the predictor is referred to as SmoltWt for convenience. In the coho model (Figure 24), SmoltWt was incorporated as a linear and quadratic term, but a linear term captures the trend for fall chinook and spring chinook (Figures 25 and 26). The decision to model the relationship as quadratic in the coho model was based on the highly significant deviance gain (Table 6), as well as exploring this relationship in models where release year and geographical factors are also included.

The fitted coho survival rate optimizes around 13 g and the slope of the SmoltWt effect was significantly steeper for spring chinook than fall chinook. If the quadratic term would be incorporated in the fall chinook and spring chinook models, the fitted curve would take a U-shape (negative $\hat{\beta}_1$ and positive $\hat{\beta}_2$). High fitted survival rate of extremely lightweight smolts is neither easy to justify biologically nor from the data and is more likely related to effects not included in the model.

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[7] Although $\log_{10}$ is used for axis ticks on graphs, all regression coefficients refer to the natural logarithm.

One problem, especially in the coho model, is the clumped univariate distribution of SmoltWt, with only 12% of the datapoints outside the 10–50 g region, but these are the data available. When looking at the fitted lines on the scatterplots it is important to keep in mind that the datapoints carry different regression weights ($Tagged \times Fraction$). The deviance residuals take this into account and their distribution (lower panels in Figures 24–26) shows no major problems.

4.3 SST Model

The coastal sea surface temperature in the summer ranges from around 11°C to 16°C, with the exception of groups released into the Yukon River (Figure 4) which experience Bering Sea temperatures as low as 5°C. The median SST is around 14°C for all species and types. For coho and spring chinook, the scatterplots of survival rate on SST (Figures 27, 29, and 30) show a much clearer pattern than was seen for SmoltWt, but the relationship looks weaker in the case of fall chinook (Figure 28). The analysis of deviance (Table 7) verifies these findings, as the deviance gain for coho and spring chinook is greater by incorporating SST than SmoltWt, but vice versa for fall chinook.

The spring chinook data from Yukon River are scarce (87 CWT groups) and all SST values below 11.5°C are from this area only. It seems hard to fit a line through the survival rate pattern of these groups, for example those at the very lowest SST, where six datapoints have 0% survival rate and three have 0.3%. However, when the spring chinook model was refitted while excluding all Yukon River groups, the fitted curve changed very little (dotted line in Figure 29, solid line in Figure 30). In other words, the low Yukon River survival rates (53 CWT groups with 0% survival) agree with the overall SST trend.

One way to assess the explanatory power of the SST model is to compare its gained deviance to a model incorporating release year as a factor, asking the question: how much of the annual variability can be explained with SST? From the time series of average survival rate presented in Section 3, it is clear that the year effect differs substantially depending on the domain. Hence, the year-specific model incorporates every release year/domain combination as an interaction factor called Year:Domain. By using close to one hundred degrees of freedom, it explains a large part of the overall deviance (Table 8), but the gained deviance of the coho and spring chinook SST models is high in comparison, over 40% of the Year:Domain predictive power, but only 12% for fall chinook, implying a weaker relationship between survival rate and SST.

The value of SST where the fitted curves optimize can be calculated from the regression coefficients by differentiating the regression formula:

$$E(Survival) = \exp(\hat{\beta}_0 + \hat{\beta}_1 SST + \hat{\beta}_2 SST^2)$$

$$\frac{\mathrm{d}}{\mathrm{d}\,SST}\log E(Survival) = \hat{\beta}_1 + 2\hat{\beta}_2 SST \;\Rightarrow\; \widehat{SST}_{\mathrm{opt}} = \frac{-\hat{\beta}_1}{2\hat{\beta}_2} \qquad \text{(Eq. 8)}$$

The fitted survival rate optimizes at 13.0°C for coho, 13.1°C for fall chinook, and 11.9°C for spring chinook (Figure 31, Table 7). To calculate the standard error of these estimates, the delta method was used (Casella and Berger 1990, p. 331), based on Taylor series approximation:

$$\widehat{SST}_{\text{opt}} = -\frac{1}{2}\left(\frac{\hat{\beta}_1}{\hat{\beta}_2}\right)$$

$$\widehat{\text{Var}}(\widehat{SST}_{\text{opt}}) \approx \frac{1}{4} \times \left[\begin{array}{c} \widehat{\text{Var}}(\hat{\beta}_1)\left(\dfrac{\delta\,\hat{\beta}_1/\hat{\beta}_2}{\delta\hat{\beta}_1}\right)^2 + \widehat{\text{Var}}(\hat{\beta}_2)\left(\dfrac{\delta\,\hat{\beta}_1/\hat{\beta}_2}{\delta\hat{\beta}_2}\right)^2 \\ +2\widehat{\text{Cov}}(\hat{\beta}_1,\hat{\beta}_2)\left(\dfrac{\delta\,\hat{\beta}_1/\hat{\beta}_2}{\delta\hat{\beta}_1}\right)\left(\dfrac{\delta\,\hat{\beta}_1/\hat{\beta}_2}{\delta\hat{\beta}_2}\right) \end{array} \right] \qquad \text{(Eq. 9)}$$

$$\approx \widehat{SST}_{\text{opt}}{}^2 \times \left[\frac{\widehat{\text{Var}}(\hat{\beta}_1)}{\hat{\beta}_1^2} + \frac{\widehat{\text{Var}}(\hat{\beta}_2)}{\hat{\beta}_2^2} - \frac{2\widehat{\text{Cov}}(\hat{\beta}_1,\hat{\beta}_2)}{\hat{\beta}_1 \times \hat{\beta}_2} \right]$$

where $\widehat{Var}(\hat{\beta}_1)$ and $\widehat{Var}(\hat{\beta}_2)$ are the estimated scaled variances of the regression coefficient estimates and $\widehat{Cov}(\hat{\beta}_1,\hat{\beta}_2)$ is the estimated scaled covariance.[8] In Table 7 the bottom row corresponds to the square root of $\widehat{Var}(\widehat{SST}_{\text{opt}})$, showing that SST_{opt} is much better determined in the coho model (SE = 0.035°C) than for fall chinook (SE = 0.165°C) or spring chinook (SE = 0.152°C).

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[8] The scale parameter and the unscaled variance-covariance matrix are supplied as output by the summary.glm function in S-PLUS.

4.4 SmoltWt + SST Model

The two predictors SmoltWt and SST are correlated ($r = 0.33$ for coho, 0.16 for fall chinook, and 0.56 for spring chinook), as smolts at lower latitudes reach a larger body size before the time of release. This creates a problem common in regression analysis of data that do not come from a designed experiment. Since the Yukon River spring chinook have both the smallest body weight (2.1 g on the average) and the lowest SST values, it becomes impossible to tell whether their low survival rates are related to one or both of these effects. These high-leverage datapoints are excluded from the spring chinook SmoltWt + SST model, which brings the correlation coefficient down to 0.41.

A variety of SmoltWt + SST models were fitted and diagnosed, including ones with one or more interaction terms. In summary, the more complicated models fitted the main trends in a similar way as the simple models, but used the extra parameters to “hunt down” outliers. Since large positive deviance residuals are likely related to effects such as different hatchery practices or especially good habitat, rather than some complex interaction between SmoltWt and SST, the simple models were selected as final models.

The coho model incorporates SmoltWt, SmoltWt^2, SST, and SST^2 (Table 9). When these effects are taken into account simultaneously, the fitted survival rate shows a joint maximum around SST = 13°C and SmoltWt = 18 g. In the fall chinook model (Table 10), the SmoltWt^2 term was not incorporated in the final model, due to the same U-shape reasons explained in Section 4.2, but the term was not significant in the spring chinook model (Table 11). The SST_{opt} confidence intervals from the SmoltWt + SST models overlap with the SST models from Section 4.3, being around 13°C for coho and fall chinook, but the SST_{opt} for spring chinook is only vaguely determined by the available data as 6.8 ± 4.2°C.

Surface plots are an efficient way to visualize the regression fit from each of the SmoltWt + SST models (Figure 32), but can be misleading if the viewer does not keep in mind where the datapoints are mainly located on the SmoltWt and SSTsummer grid. The aim of the model selection has been explanatory, and not predictive.

4.5 Segment Model for Columbia and Fraser Basins

Within the Columbia Basin, the two predictors Upstream (distance in km) and Dams are correlated ($r > 0.85$) for obvious reasons. Nevertheless, an attempt was made to separate the negative effects of Upstream and Dams by utilizing the CWT groups that have the same value for Dams, but different values for Upstream. The success was limited, due to consistent hatchery differences not related to Upstream or Dams. To take an example, these predictors cannot explain why the survival rates of fall chinook released from hatcheries such as Priest Rapids and Hagerman (Appendix C), are consistently higher than most of the hatchery further downstream with fewer dams to cross. This problem was not solved by incorporating SmoltWt as a predictor.

On a coarser scale there is still strong evidence of a negative effect of Upstream and Dams. To visualize this, the Columbia Basin was divided into four segments: Columbia below dams, Willamette River, Columbia above dams, and Snake River, ordered in ascending distance upstream (Appendix C). For comparison, the Fraser Basin was similarly divided into three segments: Lower Fraser, Thompson River, and Upper Fraser. Since there are no major dams in the Fraser Basin, one might have expected a less negative trend with distance upstream there, but the boxplots in Figure 33 show that the declining survival rate trends are strong in both Fraser and Columbia basins.

4.6 SmoltWt + SST + Upstream Model for Columbia Basin

For modelling the survival rate dynamics in Columbia Basin, Upstream was used as a proxy for the cumulative effect of distance upstream and dams. SmoltWt and SST were also used as candidate predictors for the model selection. For fall chinook, the negative relationship between SST and survival rate is apparent from a scatterplot, and the same is true for Upstream (Figure 34). When these two predictors have been incorporated in the model, SmoltWt is the next significant regression term (Table 12), followed by the quadratic terms SmoltWt^2 and SST^2. The joint optimum of fall chinook SmoltWt and SST lies around 35 g and 13.5°C.

The spring chinook scatterplots (Figure 35) show an unusually clear relationship between SmoltWt and survival rate, but also a disturbing correlation with Upstream ($r = -0.61$). This phenomenon of lightweight releases far upstream is not caused by differences in release months, which are primarily March to May for all hatcheries releasing spring chinook in the Columbia Basin. In a forward selection, SmoltWt was selected as the first predictor to incorporate in the model, its deviance gain being two times greater than for Upstream (Table 13). The second predictor to be incorporated was SST, then Upstream and $SmoltWt^2$, but the SST^2 was far from being significant. The estimated negative effect of Upstream was comparable in the two models, with a narrower confidence interval in the fall chinook model. Nevertheless, it was the spring chinook model that showed a much closer overall fit to the data, explaining 48% of the total deviance, compared with 16% for the fall chinook model, even though it uses one less degree of freedom.

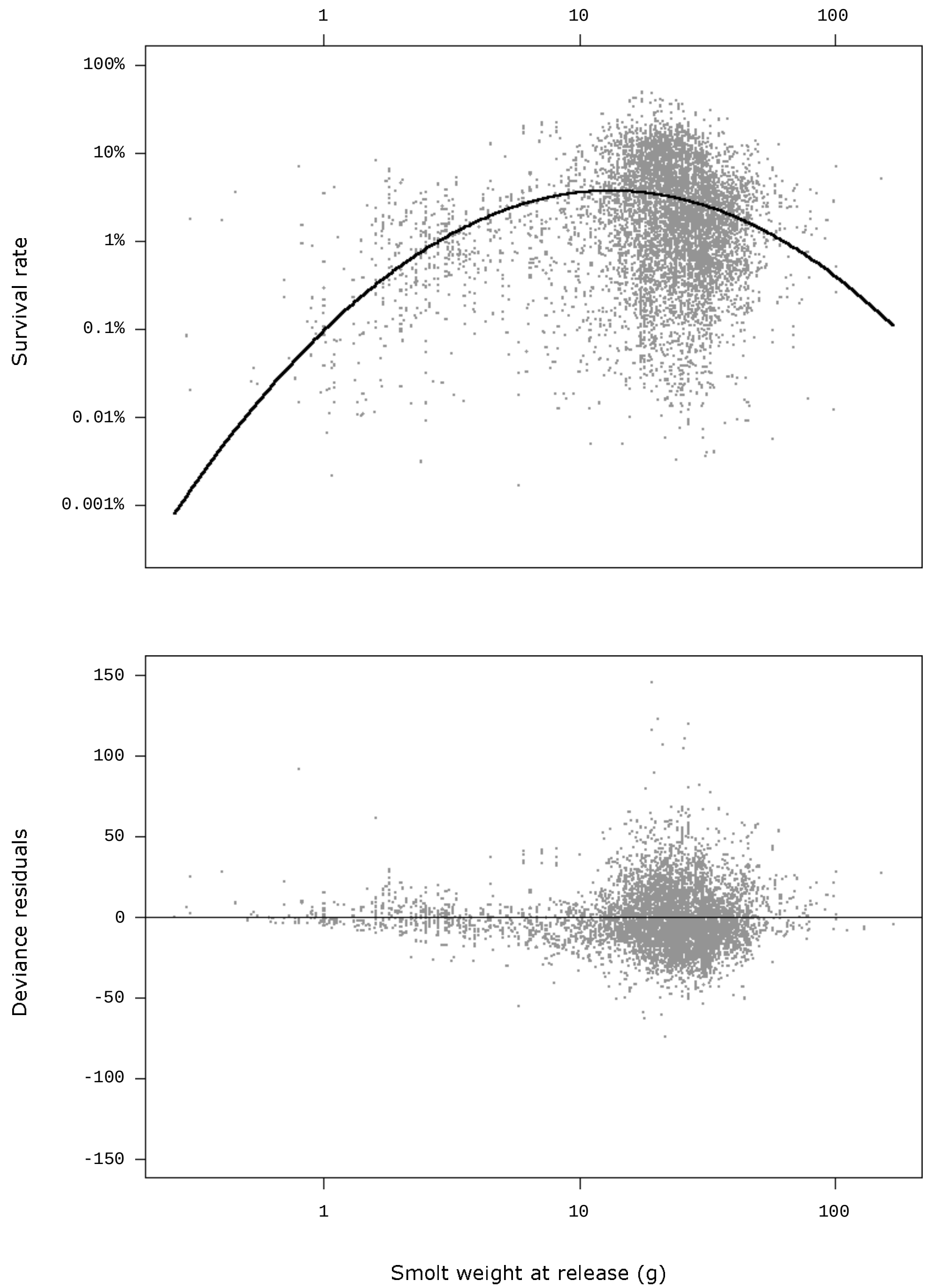

Figure 24 Fitted coho survival rate and residuals from the SmoltWt model. Datapoints with zero survival rate are omitted from the upper graph, but included in the regression computation and the residual plot.

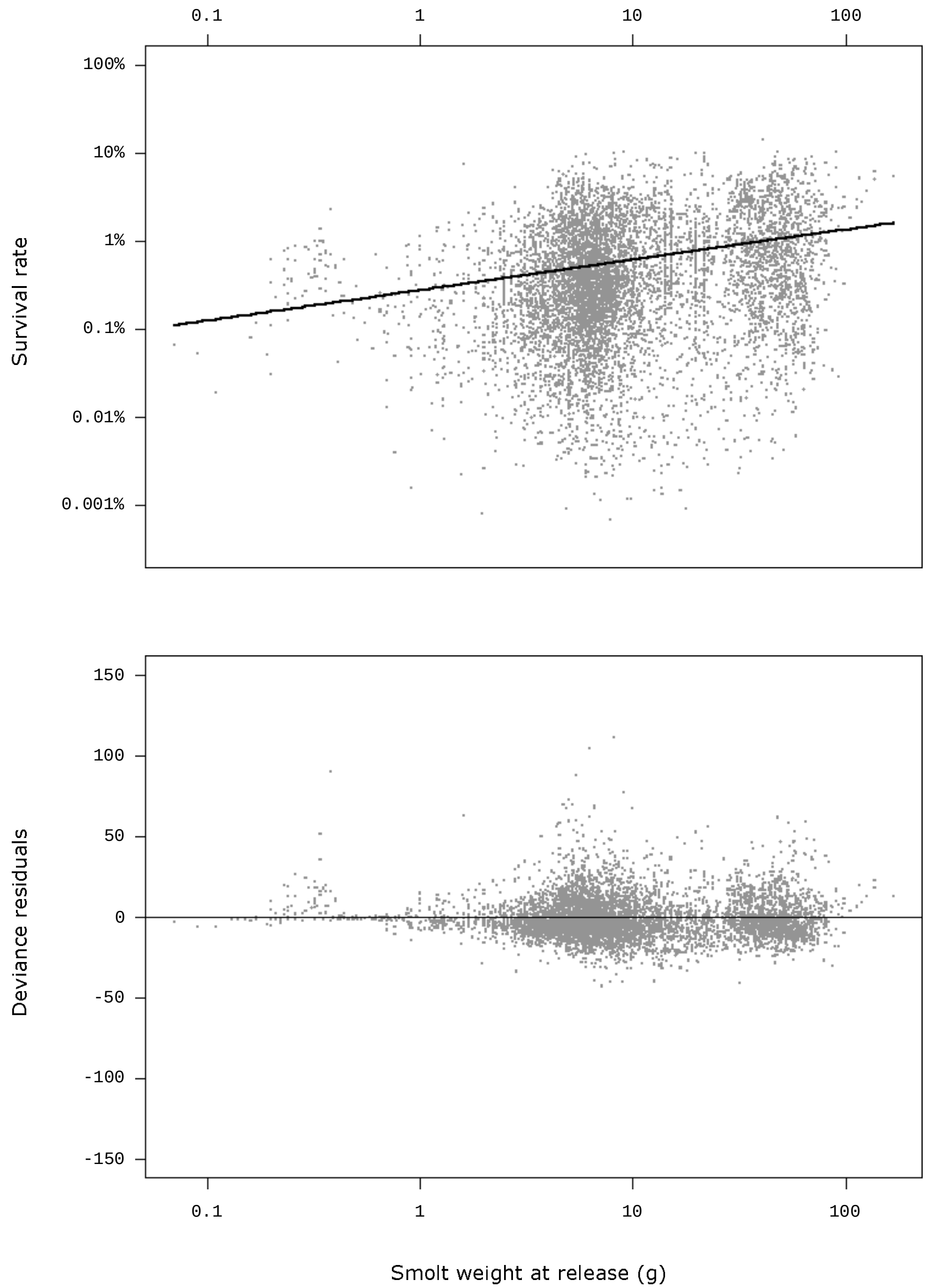

Figure 25 Fitted fall chinook survival rate and residuals from the SmoltWt model. Datapoints with zero survival rate are omitted from the upper graph, but included in the regression computation and the residual plot.

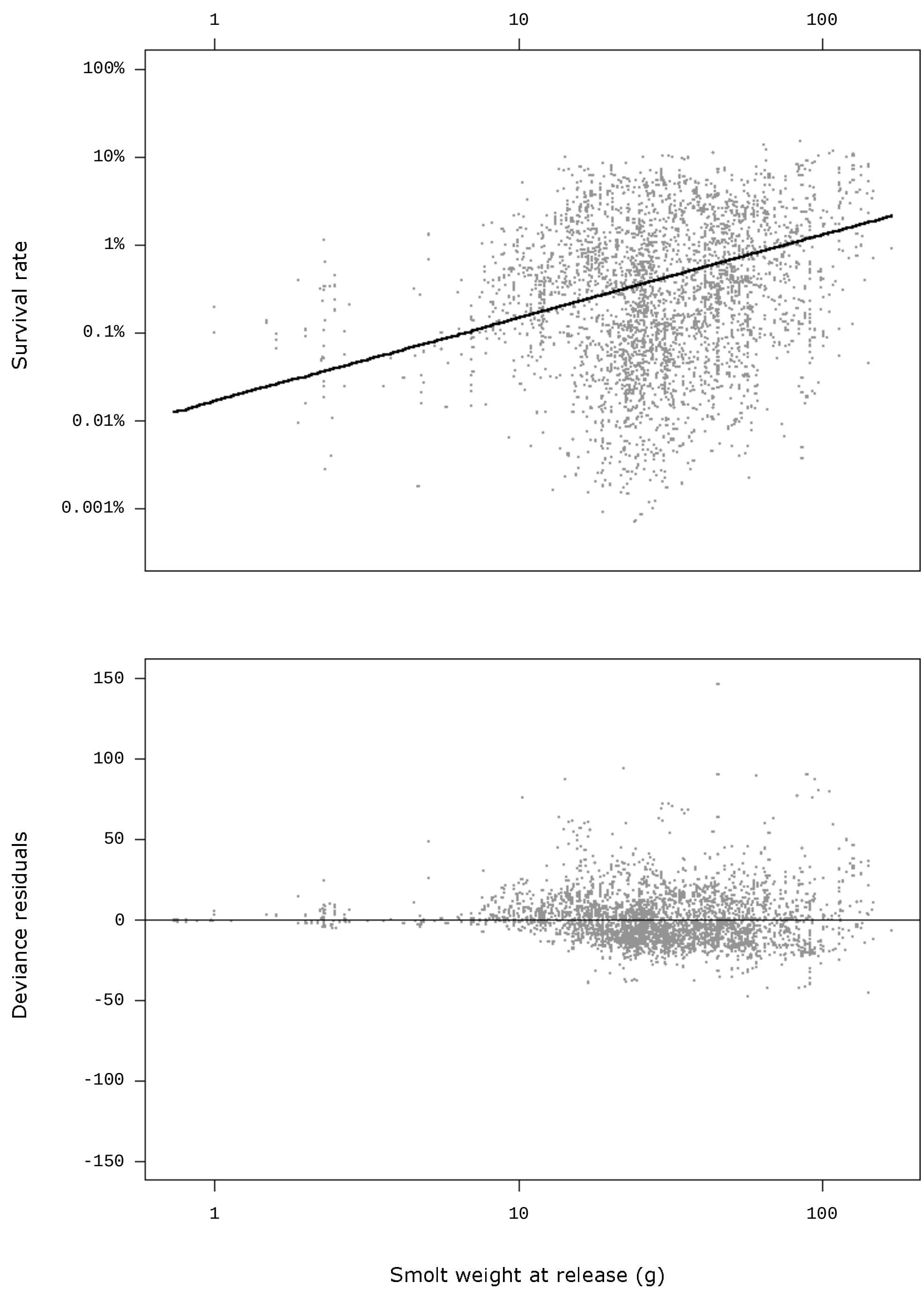

Figure 26 Fitted spring chinook survival rate and residuals from the SmoltWt model. Datapoints with zero survival rate are omitted from the upper graph, but included in the regression computation and the residual plot.

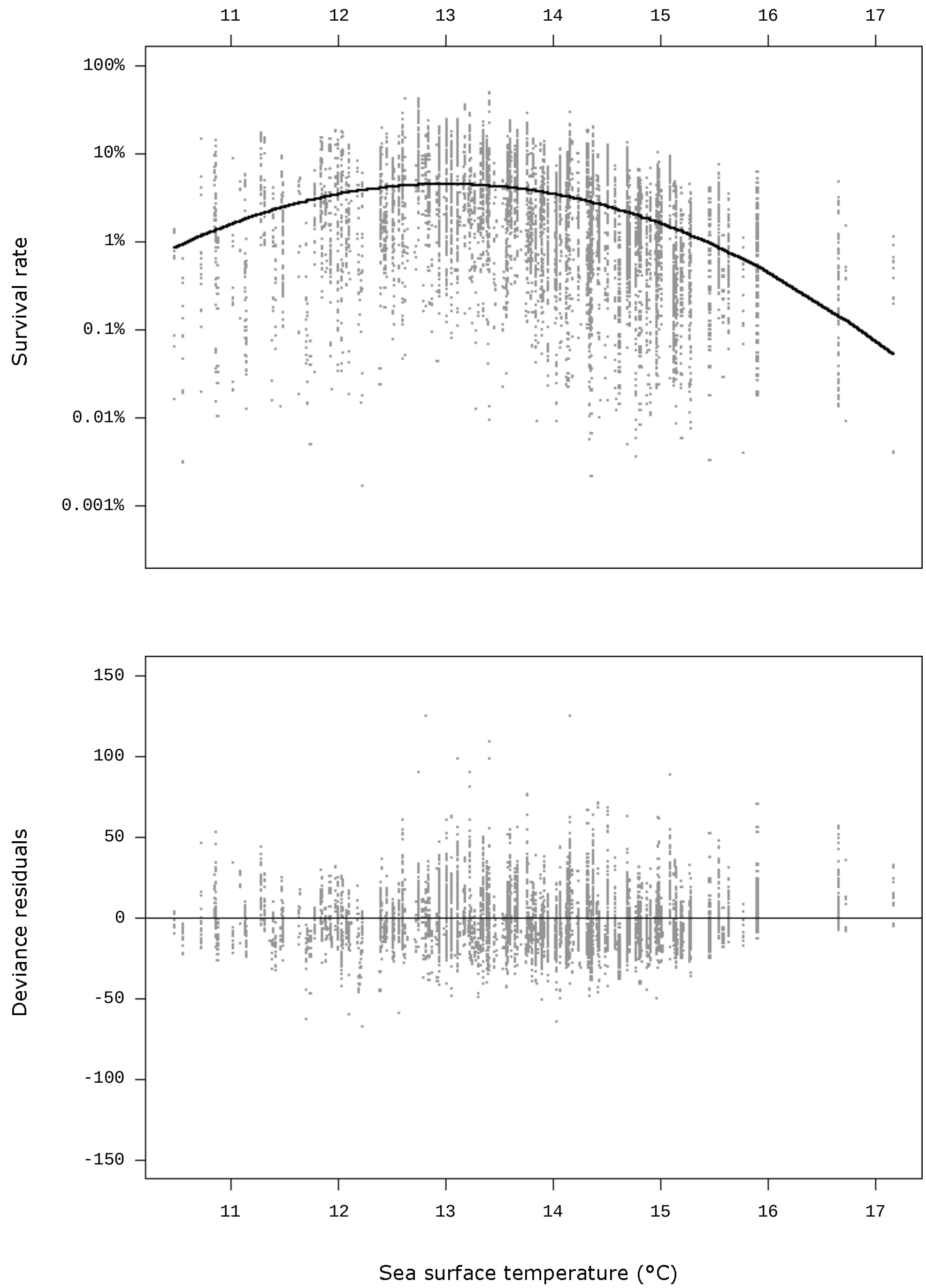

Figure 27 Fitted coho survival rate and residuals from the SST model. Datapoints with zero survival rate are omitted from the upper graph, but included in the regression computation and the residual plot.

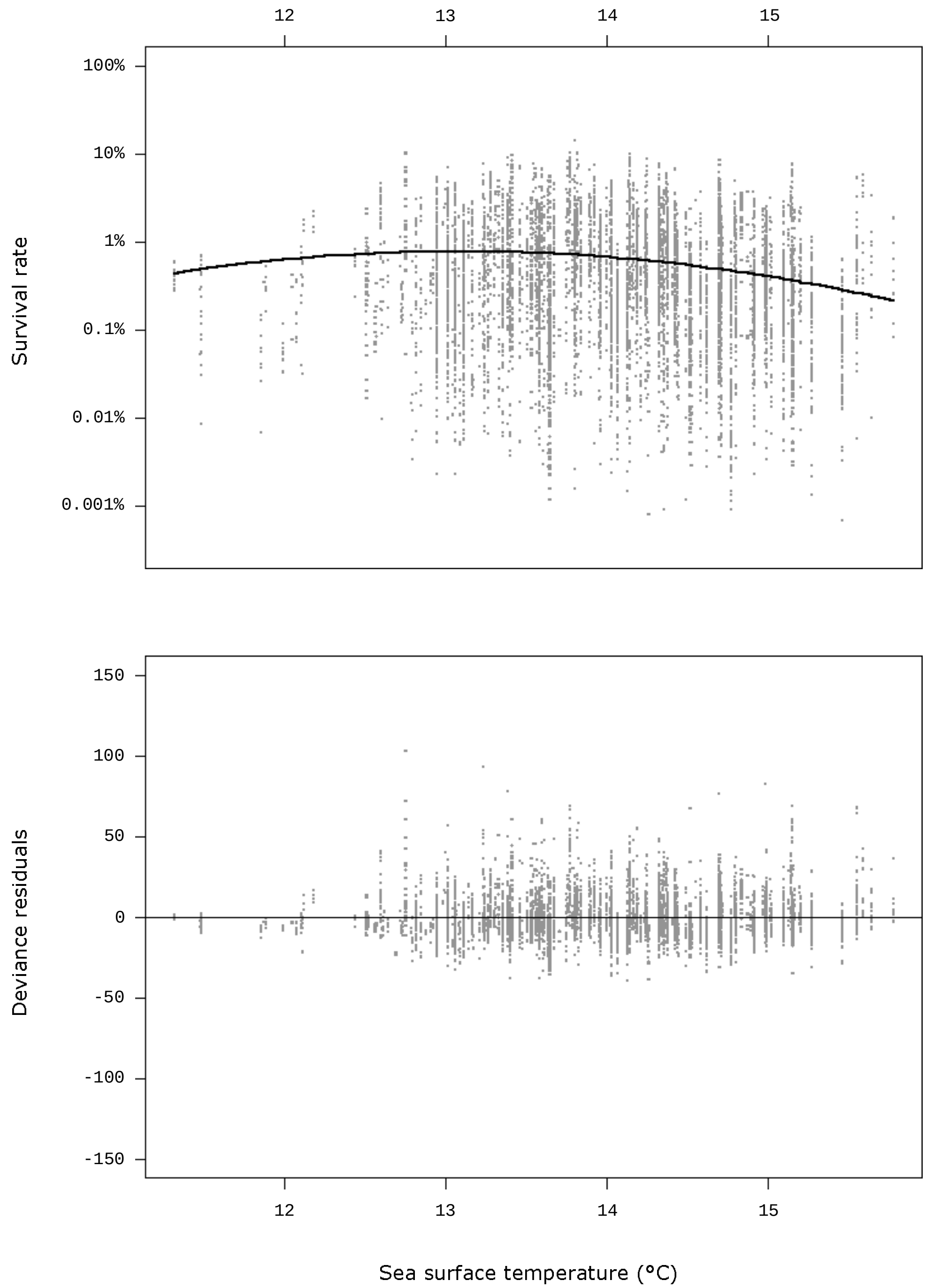

Figure 28 Fitted fall chinook survival rate and residuals from the SST model. Datapoints with zero survival rate are omitted from the upper graph, but included in the regression computation and the residual plot.

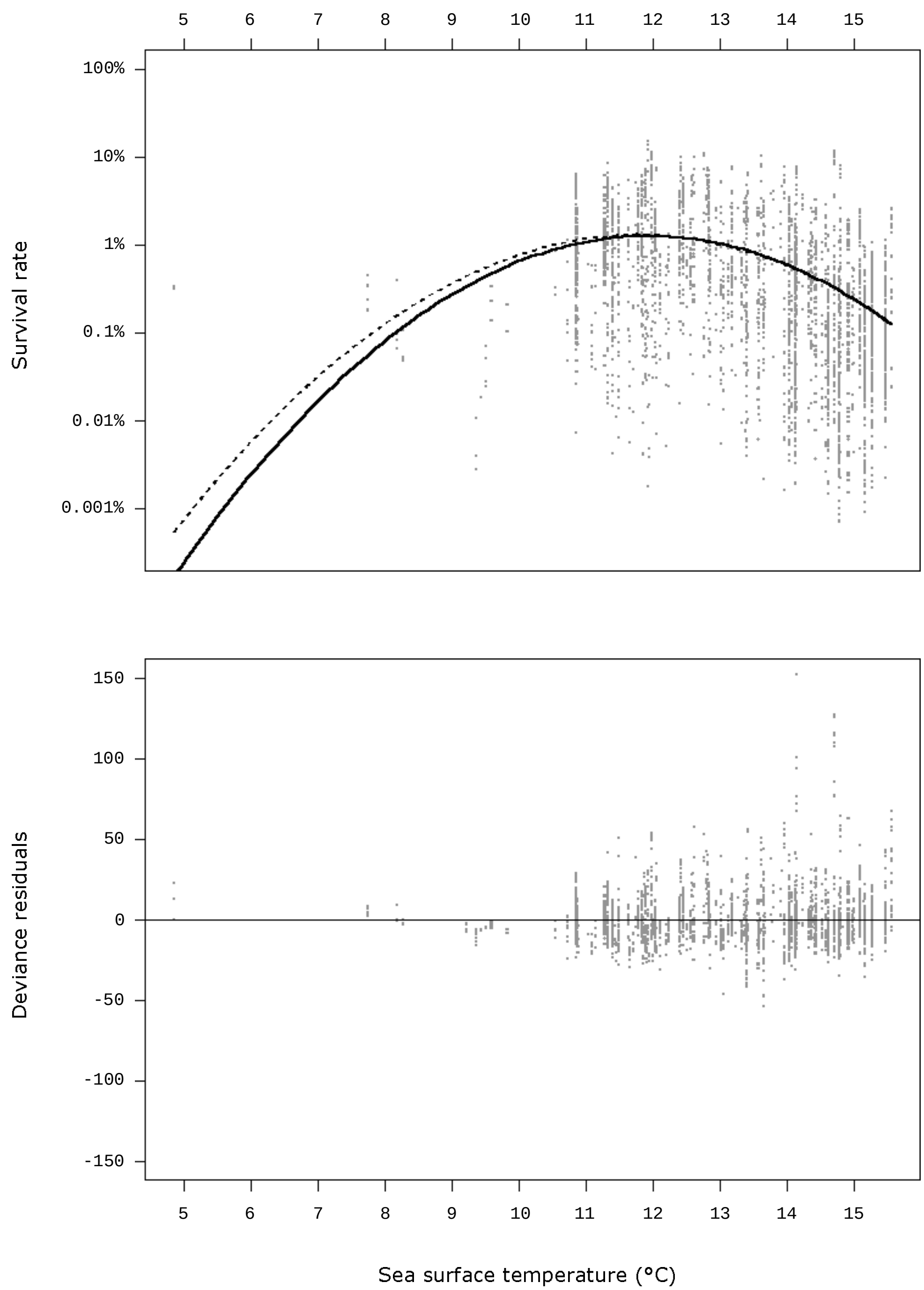

Figure 29 Fitted spring chinook survival rate and residuals from the SST model. Datapoints with zero survival rate are omitted from the upper graph, but included in the regression computation and the residual plot. The dotted line shows the fitted curve when data from Yukon River is excluded.

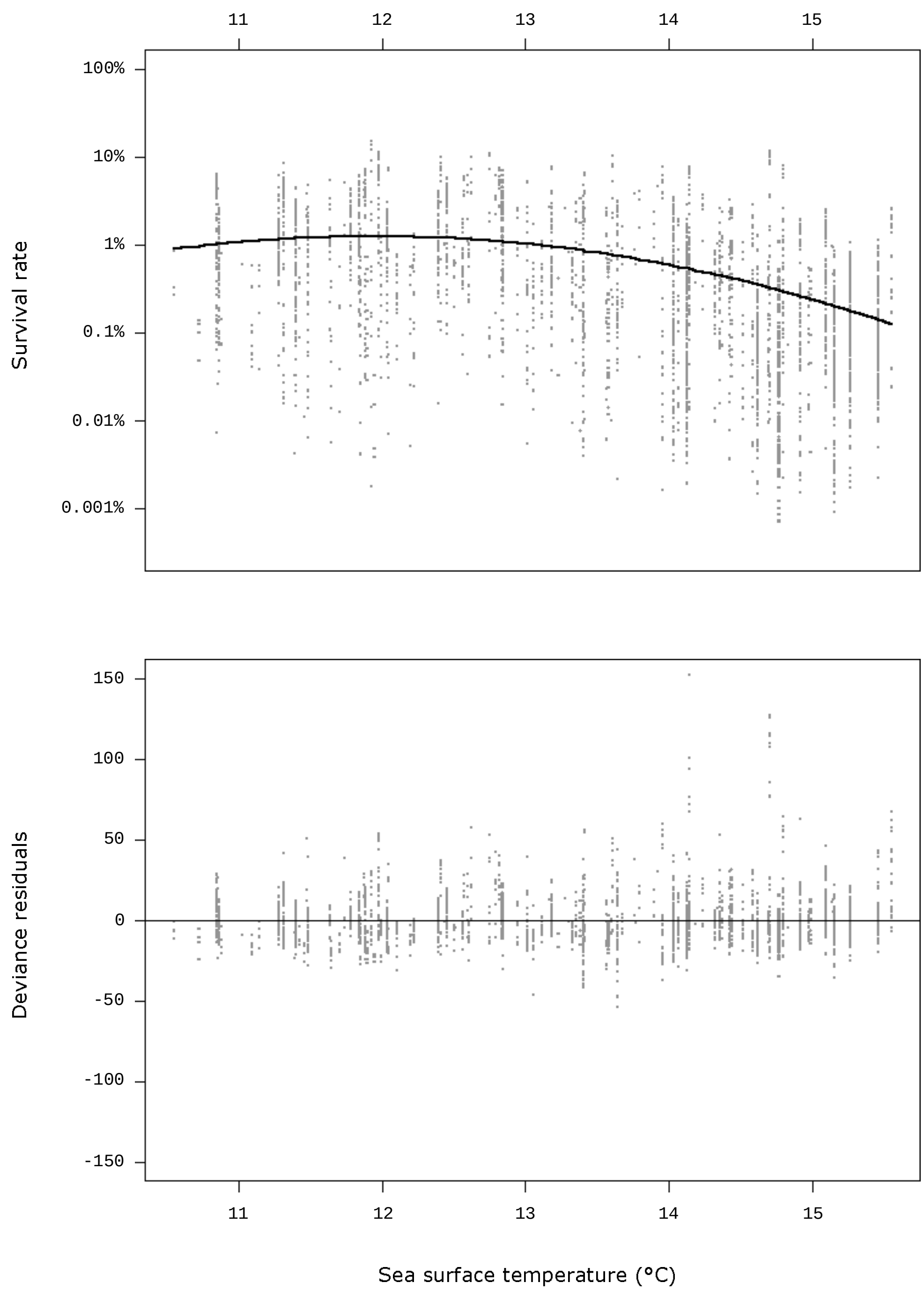

Figure 30 Fitted spring chinook survival rate and residuals from the SST model, excluding data from Yukon River. Datapoints with zero survival rate are omitted from the upper graph, but included in the regression computation and the residual plot.

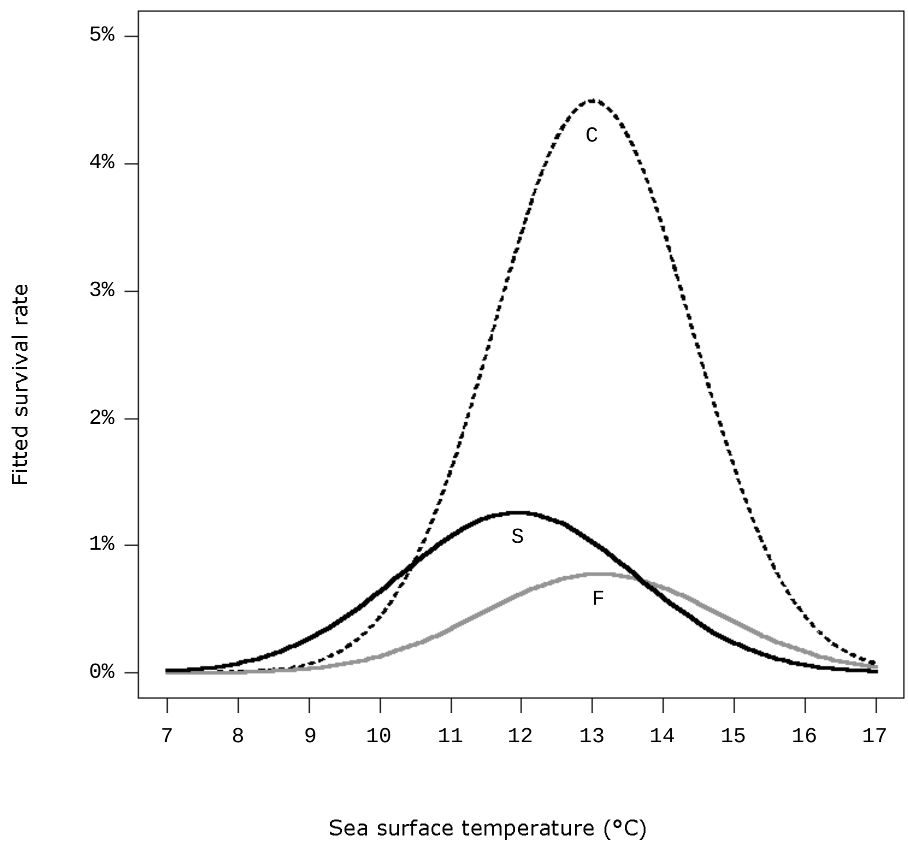

Figure 31 Fitted survival rate from the coho, fall chinook, and spring chinook SST models. Coho (C): dotted line, fall chinook (F): grey line, and spring chinook (S): solid line. The normal-curve shape comes from transforming the quadratic fit from log space.

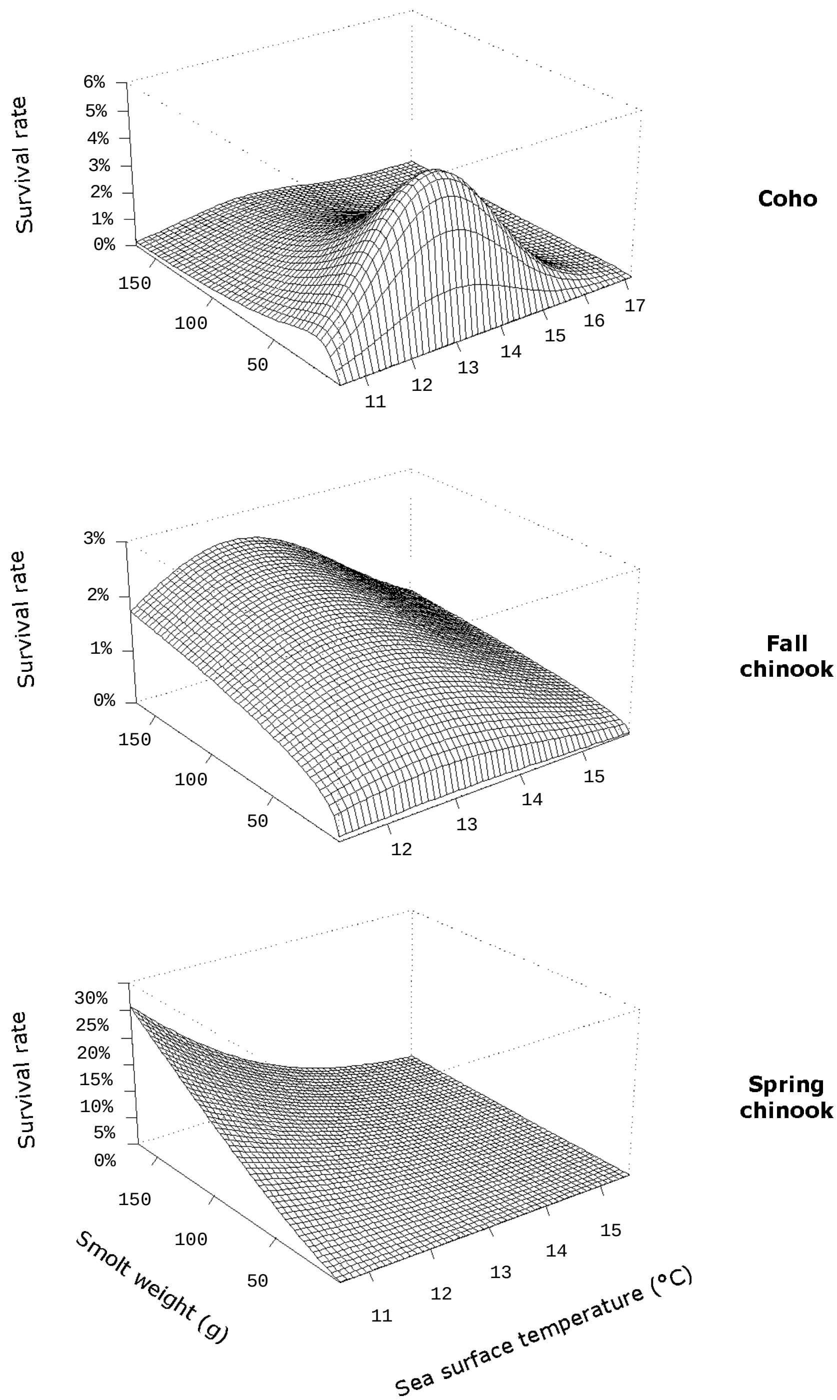

Figure 32 Fitted survival rate surfaces from the coho, fall chinook, and spring chinook SmoltWt + SST models. These surfaces represent maximum likelihood fits to the datapoints and are not meant for extrapolating predictions where no datapoints occur.

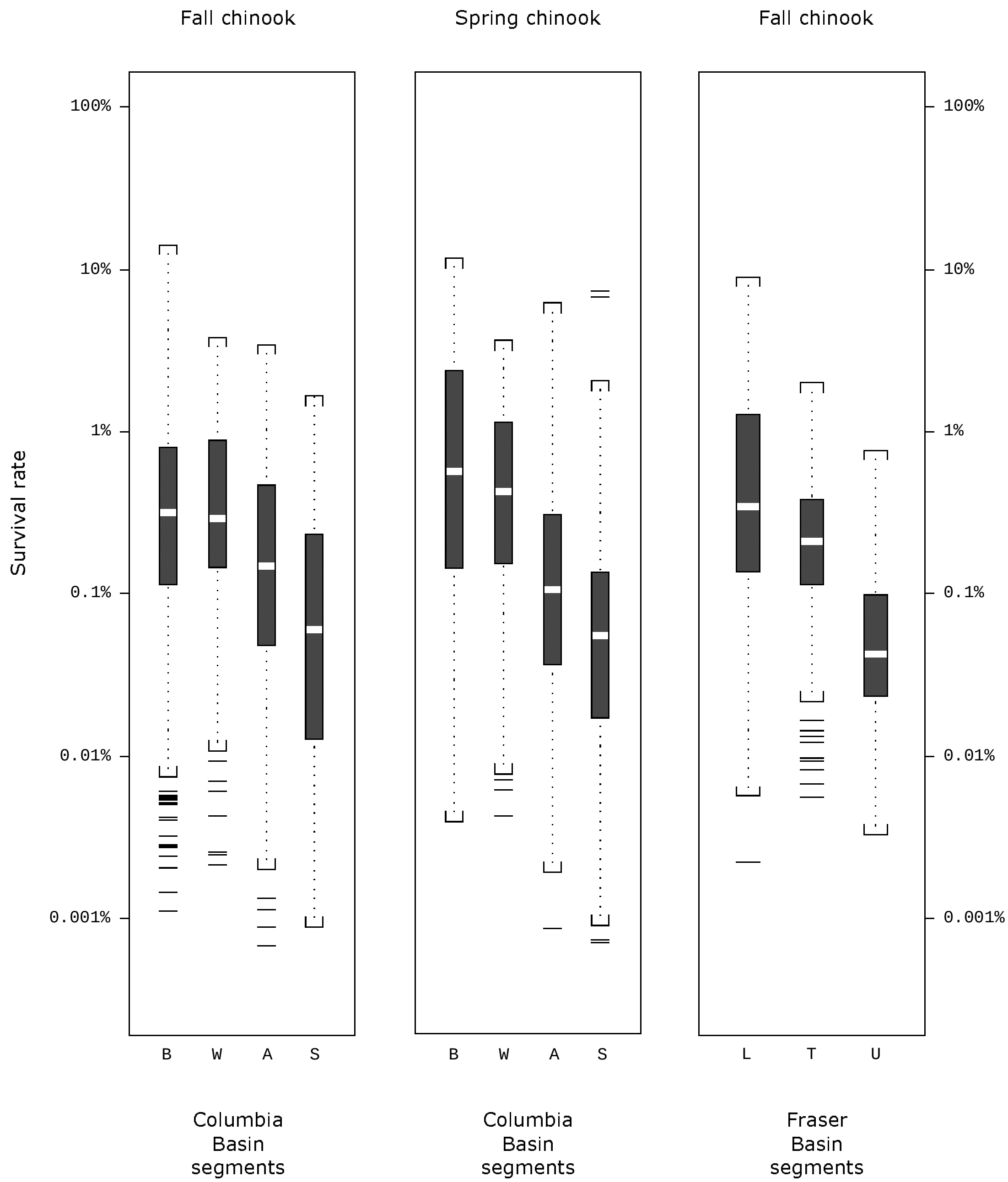

Figure 33 Boxplots of fall chinook and spring chinook survival rates in Columbia and Fraser basins, split by river segments. B: Columbia below dams, W: Willamette River, A: Columbia above dams, S: Snake River, L: Lower Fraser, T: Thompson River, U: Upper Fraser. Spring chinook releases into Fraser Basin are too few for a split boxplot.

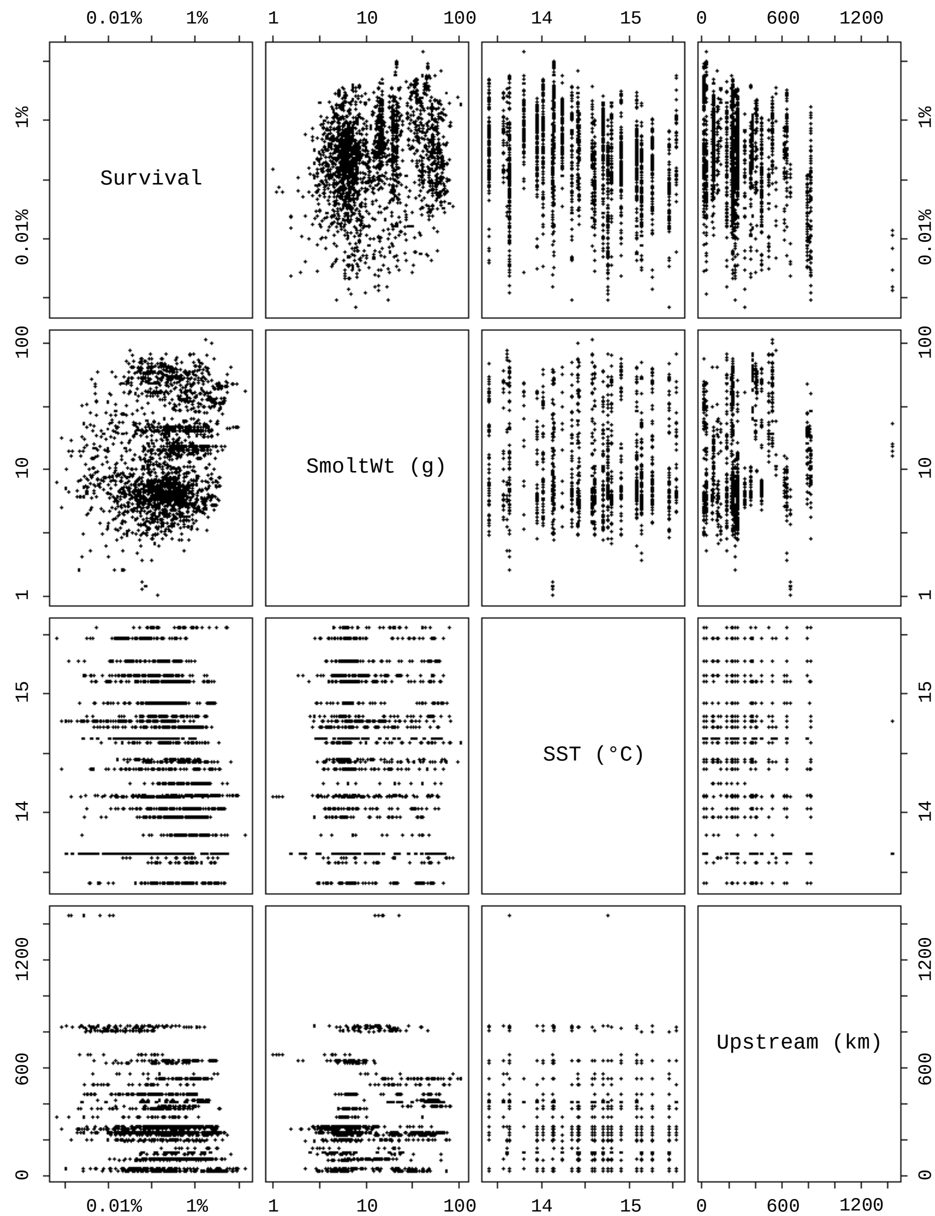

Figure 34 Scatterplot matrix of survival rate and predictors used in the fall chinook SmoltWt + SST + Upstream model for Columbia Basin. Survival and SmoltWt have logarithm axes.

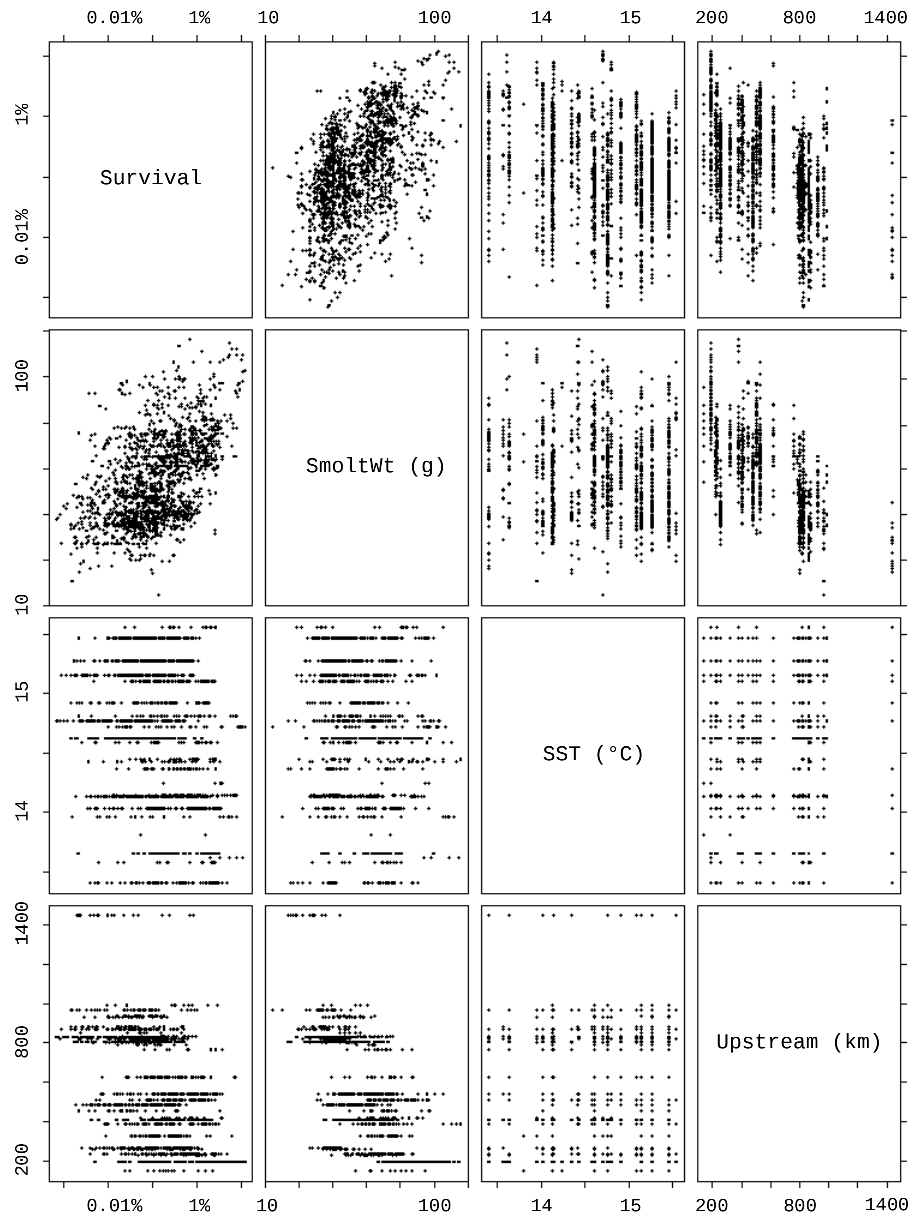

Figure 35 Scatterplot matrix of survival rate and predictors used in the spring chinook SmoltWt + SST + Upstream model for Columbia Basin. Survival and SmoltWt have logarithm axes.

Table 6 Analysis of deviance and estimated parameters from the coho, fall chinook, and spring chinook SmoltWt models. The quadratic term was only incorporated in the coho model, but the deviance gain is listed for fall chinook and spring chinook for the sake of thoroughness.

	Coho		Fall chinook		Spring chinook	
	df	*D*	*df*	*D*	*df*	*D*
Null	7 278	2 433 266	7 856	1 215 094	3 522	924 721
	Δdf	ΔD	Δdf	ΔD	Δdf	ΔD
SmoltWt	1	9 687 ***	1	73 322 ***	1	102 439 ***
SmoltWt^2	1	188 747 ***	1	11 408 ***	1	18 908 ***
	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*
φ	441.1	–	226.7	–	517.6	–
β_0	−6.948	0.244	−5.896	0.048	−8.716	0.255
β_1	2.828	0.177	0.345	0.019	0.949	0.068
β_2	−0.547	0.032				

Notes:
Standard errors of parameter estimates have been scaled, but deviances are left unscaled.
F-test is used to test significance of regression terms.

Table 7 Analysis of deviance and estimated parameters from the coho, fall chinook, and spring chinook SST models. Also listed is the derived parameter SST_{opt} locating the value of SST where the fitted survival rate optimizes.

	Coho		Fall chinook		Spring chinook	
	df	*D*	*df*	*D*	*df*	*D*
Null	7 278	2 433 266	7 856	1 215 094	3 522	924 721
	Δdf	ΔD	Δdf	ΔD	Δdf	ΔD
SST	1	177 613 ***	1	40 363 ***	1	108 849 ***
SST^2	1	283 249 ***	1	9 442 ***	1	63 256 ***
	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*
φ	344.8	–	242.3	–	490.0	–
β_0	−46.729	1.924	−35.852	5.955	−29.689	3.380
β_1	6.706	0.285	4.733	0.853	4.240	0.519
β_2	−0.258	0.010	−0.181	0.030	−0.178	0.020
SST_{opt}	13.012	0.035	13.100	0.165	11.943	0.152

Notes:
Standard errors of parameter estimates have been scaled, but deviances are left unscaled.
F-test is used to test significance of regression terms.

Table 8 Analysis of deviance from the SST models compared with the Year:Domain models. The comparison statistic is the deviance gained by incorporating the SST terms, as a proportion of the deviance gained by incorporating Year:Domain.

	Coho		Fall chinook		Spring chinook	
	df	*D*	*df*	*D*	*df*	*D*
Null	7 278	2 433 266	7 856	1 215 094	3 522	924 721
	Δdf	ΔD	Δdf	ΔD	Δdf	ΔD
SST+SST^2	2	460 862 ***	2	49 805 ***	2	172 104 ***
Year:Domain	104	1 128 514 ***	74	412 510 ***	88	392 431 ***
Comparison		41%		12%		44%

Notes:
Standard errors of parameter estimates have been scaled, but deviances are left unscaled.
F-test is used to test significance of regression terms.

Table 9 Analysis of deviance and estimated parameters from the coho SmoltWt + SST model. The regression terms are listed in forward selection order and all four were incorporated in the final model. Also listed is the derived parameter SST_{opt} locating the value of SST where the fitted survival rate optimizes.

	Coho			
	df	*D*		
Null	7 278	2 433 266		
	Δdf	ΔD		Incorporated
SST	1	177 613	***	yes
SST^2	1	283 249	***	yes
SmoltWt	1	68 272	***	yes
$SmoltWt^2$	1	111 656	***	yes
	Estimate	*SE*		
φ	335.6	–		
β_0	−48.841	1.934		
β_{WT1}	2.525	0.155		
β_{WT2}	−0.435	0.028		
β_{SST1}	6.528	0.284		
β_{SST2}	−0.252	0.010		
SST_{opt}	12.947	0.039		

Notes:
Standard errors of parameter estimates have been scaled, but deviances are left unscaled.
F-test is used to test significance of regression terms.

Table 10 Analysis of deviance and estimated parameters from the fall chinook SmoltWt + SST model. The regression terms are listed in forward selection order, but SmoltWt^2 was not incorporated. Also listed is the derived parameter SST_{opt} locating the value of SST where the fitted survival rate optimizes.

	Fall chinook		
	df	*D*	
Null	7 856	1 215 094	
	Δdf	ΔD	Incorporated
SmoltWt	1	73 322 ***	yes
SST	1	57 191 ***	yes
SmoltWt^2	1	9 196 ***	no
SST^2	1	8 223 ***	yes
	Estimate	*SE*	
φ	203.1	–	
β_0	−32.952	5.358	
β_{WT1}	0.379	0.018	
β_{SST1}	4.259	0.767	
β_{SST2}	−0.166	0.027	
SST_{opt}	12.836	0.203	

Notes:
Standard errors of parameter estimates have been scaled, but deviances are left unscaled.
F-test is used to test significance of regression terms.

Table 11 Analysis of deviance and estimated parameters from the spring chinook SmoltWt + SST model. The regression terms are listed in forward selection order and SmoltWt^2 was not incorporated in the final model. Data from Yukon River are not used. Also listed is the derived parameter SST_{opt} locating the value of SST where the fitted survival rate optimizes.

	Spring chinook		
	df	*D*	
Null	3 435	920 227	
	Δdf	ΔD	Incorporated
SST	1	146 523 ***	yes
SmoltWt	1	210 178 ***	yes
SST^2	1	2 582 **	yes
SmoltWt^2	1	53 ns	no
	Estimate	*SE*	
φ	280.0	–	
β_0	−9.416	3.001	
β_{WT1}	1.247	0.047	
β_{SST1}	0.717	0.465	
β_{SST2}	−0.053	0.018	
SST_{opt}	6.770	2.147	

Notes:
Standard errors of parameter estimates have been scaled, but deviances are left unscaled.
F-test is used to test significance of regression terms.

Table 12 Analysis of deviance and estimated parameters from the fall chinook SmoltWt + SST + Upstream model for Columbia Basin. The regression terms are listed in forward selection and all five were incorporated in the final model. Also listed is the derived parameter SST_{opt} locating the value of SST where the fitted survival rate optimizes.

	Fall chinook		
	df	*D*	
Null	2 463	340 881	
	Δdf	ΔD	Incorporated
SST	1	19 549 ***	yes
Upstream	1	17 216 ***	yes
SmoltWt	1	12 232 ***	yes
$SmoltWt^2$	1	3 030 ***	yes
SST^2	1	2 528 ***	yes
	Estimate	*SE*	
φ	191.2	–	
β_0	−73.832	21.270	
β_{WT1}	1.325	0.272	
β_{WT2}	−0.186	0.050	
β_{SST1}	9.941	2.963	
β_{SST2}	−0.367	0.103	
β_{UPST}	-1.616×10^{-3}	0.165×10^{-3}	
SST_{opt}	13.526	0.251	

Notes:
Standard errors of parameter estimates have been scaled, but deviances are left unscaled.
F-test is used to test significance of regression terms.

Table 13 Analysis of deviance and estimated parameters from the spring chinook SmoltWt + SST + Upstream model for Columbia Basin. The regression terms are listed in forward selection and SST^2 was not incorporated in the final model.

	Spring chinook			
	df	*D*		
Null	1 875	532 776		
	Δdf	ΔD		Incorporated
SmoltWt	1	216 930	***	yes
SST	1	26 189	***	yes
Upstream	1	9 644	***	yes
SmoltWt^2	1	1 842	**	yes
SST^2	1	84	ns	no
	Estimate	*SE*		
φ	270.7	–		
β_0	-7.376	2.397		
β_{WT1}	4.611	1.139		
β_{WT2}	−0.370	0.144		
β_{SST1}	−0.663	0.063		
β_{UPST}	-1.756×10^{-3}	0.301×10^{-3}		

Notes:
Standard errors of parameter estimates have been scaled, but deviances are left unscaled.
F-test is used to test significance of regression terms.

5 DISCUSSION

The effects of the three predictors involved in the regression analysis (SmoltWt, SST, and Upstream) have all been studied before, as reviewed earlier. The approach of the study presented here differs primarily in scope, by including release and recovery data from over two hundred hatcheries from Yukon River in the north to San Joaquin River in the south, and also by fitting coho and chinook regression models side by side. The generalizations that come with this broad scope can be both praised and criticized; in an attempt to capture global trends some important local trends are ignored, such as different hatchery rearing methods and watershed characteristics. The problem of separating the effects of the two predictors Upstream and Dams in Columbia Basin is an example where local trends play a large role, and the best approach would be a designed experiment, perhaps using passive integrated transponder (PIT) tags.

Exploring the relationship between survival rate and climate effects, on the other hand, is best approached on a large scale to ensure a wide range of climate observations. The regression analysis used in this study views each coded wire tag (CWT) as one datapoint, instead of aggregating the release and recovery data into a single annual index for a large region, as is done with the Oregon Production Index (OPI), a dataset commonly used for analyzing climate effects on coho survival rate. Only in the disaggregated form is it possible to relate CWT groups to different values of SST, according to the geographical location of the releasing hatchery.

The scatterplots of survival rate and SST (Figures 27–30) seem straightforward enough, but where the relationship looks clear it owes much to the preparatory work on both variables. The filters applied to the CWT data exclude a few thousand release groups whose survival rate is highly uncertain due to a small group size, as well as releases from facilities showing very low level of activity. Some of the release groups included in the study are of release type “E”, for experimental, but the survival rate pattern of these groups is not significantly different from other release types.[9] By dividing the coastline into 13 quadrats, the SST predictor carries both temporal and spatial contrast, unlike many other climate predictors where one value per year applies to the whole North Pacific, such as the ENSO (El Niño Southern Oscillation) index, PDO (Pacific Decadal Oscillation) index, and the intensity of the Aleutian Low.

The relationship between coho survival rate and SST explains 41% of the regional and annual variation and the fitted survival rate optimizes around 13°C. An optimal window is also found for fall chinook around the same temperature, but the relationship is much weaker, explaining only 12% of the regional and annual variation. Spring chinook survival rates show a strong relationship with SST, explaining 44% of the regional and annual variation, with a negative effect of high temperatures but no clear optimum. Climate conditions seem to play a large role determining coho and spring

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[9] $p > 0.05$, t-test of β_{TYPE} coefficients from Survival~Type+Year:Domain model.

chinook survival rates, but effects other than climate seem to be more important for fall chinook. One of the reasons behind this is that fall chinook groups are released at various times during the year; although more than half are released in May and June, many groups are not released until October and November. The SST relationship becomes somewhat stronger when the late releases are excluded from the regression.

A simple comparison of long-term and short-term trends of SST (Figure 9 and Table 4) and survival rate (Figures 14, 18, 22) shows consistency with the coho and chinook regression models. In regions south of Alaska, the long-term trend has been increasing SST and declining survival rates, but the trends are opposite in Alaska. These inverse responses can be explained with the optimal climate windows estimated for coho and fall chinook. Likewise, the short-term drop in SST during the mid 1980s corresponds to increasing survival rates south of Alaska and declining survival rates in Alaska. Given these observations, and the similar trends of wild and hatchery salmon (Figure 23 in this study, Nickelson 1986, and Emlen et al. 1990), it seems likely that the decline in wild salmon abundance in the 1990s was due in considerable part to changes in ocean conditions and increases in wild stock abundance may be expected if ocean conditions change.

Little is known about the ecological dynamics that link SST and survival rate, but SST is correlated with a suite of physical and biological factors in the ocean. Components that could be of importance are upwelling, primary production, and multispecies interactions leading to predation and competition with coho and chinook salmon, especially during the first months after hatchery release. SST is a useful proxy of the ecological dynamics, a consistent, readily available dataset with spatial and temporal contrast.

The results from this study give rise to ecological questions about when, where, and how juvenile salmon mortalities occur. The most direct way to study this is in the field, by sampling or observing outmigrating smolts and other animals in their environment. If such studies would be replicated in different regions and years, the data would not only rule out certain ecological hypotheses and generate new ones, but models could be developed to link climate more directly to salmon survival rates. Decision making in watershed restoration can be greatly enhanced by analyzing marine survival rates to seperate the different factors affecting wild stock abundance. New release and recovery data are continuously added to the CWT database, and its value for ecological modelling increases at the same pace.

Glossary

The following list of definitions is mainly intended for keywords used in this study that are not found in standard textbooks in salmon biology or statistics.

Actual recoveries
Number of coded wire tags physically recovered from a CWT group and returned to an agency for analysis.
[Cf. *Tagged, Expanded recoveries, Implied recoveries, Survival rate*]

Aleutian Low
Low pressure center that dominates atmospheric circulation in the North Pacific and shows correlation with catches of diverse fish species.

Area
20 mutually exclusive geographical entities defined for this study to group hatcheries. Each area contains one or more localities.
[Cf. *Domain, Realm, Area, Locality*]

Brood year
Year in which a CWT group is "born", in the sense of egg fertilization.
[Cf. *Release year*]

CWT
Coded wire tag, a 1.0 mm wire inserted into the snouts of some smolts before release.

CWT group
A group of smolts released from a hatchery, some of which have been tagged with identical coded wire tags. In the rare case of wild CWT tagging studies, a group of wild smolts tagged and released.
[Cf. *Tagged, Actual recoveries, Expanded recoveries, Implied recoveries, Survival rate*]

Dams
Regression predictor, the number of dams between the release site of a CWT group and the ocean. Only defined for the Columbia Basin.
[Cf. *Upstream*]

Domain
4 mutually exclusive geographical entities defined for this study to group hatcheries. Each domain contains one or more realms.
[Cf. *Domain, Realm, Area, Locality*]

ENSO
El Niño Southern Oscillation index, describing the SST conditions in the central Pacific Ocean along the equator. Warm conditions correspond to El Niño events, cool conditions to La Niña events.

Expanded recoveries
Estimated number of coded wire tags recovered from a CWT group, by using sample fractions and other correction factors.
[Cf. *Tagged, Actual recoveries, Implied recoveries, Survival rate*]

Hatchery
Facility where salmon are reared, tagged, and released.

Implied recoveries
Estimated number of tagged individuals of a CWT group that survived to a adulthood, defined as 3 years old for coho and fall chinook, and 4 years old for spring chinook. Recoveries at other ages are standardized by using natural mortality rates.
[Cf. *Tagged, Actual recoveries*, *Expanded recoveries*, *Survival rate*]

Locality
47 mutually exclusive geographical entities defined for this study to group hatcheries. Each locality contains one or more hatchery.
[Cf. *Domain, Realm, Area, Locality*]

OPI
Oregon Production Index, a defined fishing area ranging from Columbia River to northern California. Summary statistics from this area are used for research and management purposes.

PDO
Pacific Decadal Oscillation index, the main principal component summarizing the trends of various climate variables in the Pacific Ocean.

Quadrat
[See *SST quadrat*]

Realm
9 mutually exclusive geographical entities defined for this study to group hatcheries. Each realm contains one or more areas.
[Cf. *Domain, Realm, Area, Locality*]

Release group
[See *CWT group*]

Release year
Year in which a CWT group is released from a hatchery.
[Cf. *Brood year*]

Segment
4 mutually exclusive parts of the Columbia Basin and 3 mutually exclusive parts of the Fraser Basin defined for this study to visualize the spatial trends of chinook survival rates in these basins, with respect to distance upstream and number of dams.

Smolt
For the purposes of this study, a juvenile salmon released from a hatchery. In the strictest sense, the salmon life history stage between fry and ocean phase.

SmoltWt
Regression predictor, the average individual smolt weight (g) at the time of release.

SST
Regression predictor, the average sea surface temperature (°C) in an SST quadrat during the time period from 1 June to 30 September.

SST quadrat
Geographical region, 2° latitude by 2° longitude, used in this study to relate hatcheries to SST measurements, via the corresponding estuaries.

Survival rate
Estimated proportion of tagged individuals of a CWT group that survived to a adulthood, defined as 3 years old for coho and fall chinook, and 4 years old for spring chinook. Calculated as Implied recoveries divided by Tagged.
[Cf. *Tagged, Actual recoveries, Expanded recoveries, Implied recoveries*]

Tag code
Binary marks engraved in the coded wire tag, in order to identify which CWT group a recovered individual belonged to.

Tagged
Number of individuals of a CWT group that were tagged.
[Cf. *Actual recoveries, Expanded recoveries, Implied recoveries, Survival rate*]

Type
Based on life history characteristics, chinook salmon are divided into ocean-type (fall chinook) and stream-type (spring chinook). Also known as “race” or “run”.

Upstream
Regression predictor, the distance upstream as the river flows. Only defined for Columbia and Fraser basins.

Upwelling
Upwelling, measured in m^3s^{-1} per 100 m of coastline, causes cool and nutrient-rich sea to reach the surface. It shows a negative correlation with SST and a positive correlation with ecosystem productivity.

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Appendix A

List of Hatcheries, with Geographical Information

Label	Hatchery	Hatchery Code	Domain	Realm	Area	Locality
AKY-01	Klondike River	2FN YUKNH2194	Alaska and Yukon	Subarctic	Yukon River	Yukon River
AKY-02	McIntyre Creek	2FN YUKNH3156	Alaska and Yukon	Subarctic	Yukon River	Yukon River
AKY-03	Whitehorse	2FN YUKNH0163	Alaska and Yukon	Subarctic	Yukon River	Yukon River
AKY-04	Crooked Creek	1F2 244 3010050024	Alaska and Yukon	Subarctic	W Alaska	Cook Inlet
AKY-05	Trail Lakes	1F2 244 3010010225	Alaska and Yukon	Subarctic	W Alaska	Cook Inlet
AKY-06	Elmendorf	1F2 247 5010060	Alaska and Yukon	Subarctic	W Alaska	Cook Inlet
AKY-07	Fort Richardson	1F2 247 5010060999	Alaska and Yukon	Subarctic	W Alaska	Cook Inlet
AKY-08	Big Lake	1F2 247 5010330010	Alaska and Yukon	Subarctic	W Alaska	Cook Inlet
AKY-09	Wally Noerenberg	1F2PW223 40	Alaska and Yukon	Subarctic	W Alaska	Pr William Sound
AKY-10	Solomon Gulch	1F2PW221 6011360	Alaska and Yukon	Subarctic	W Alaska	Pr William Sound
AKY-11	Jerry Myers	1F1NE115 3410310	Alaska and Yukon	SE Alaska	SE Alaska	Lynn Canal
AKY-12	Auke Creek	1F1NE111 5010420999	Alaska and Yukon	SE Alaska	SE Alaska	Lynn Canal
AKY-13	Gastineau	1F1NE111 4010150999	Alaska and Yukon	SE Alaska	SE Alaska	Lynn Canal
AKY-14	Snettisham	1F1NE111 33	Alaska and Yukon	SE Alaska	SE Alaska	Lynn Canal
AKY-15	Starrigavan	1F1NW113 4110150	Alaska and Yukon	SE Alaska	SE Alaska	Baranof Island
AKY-16	Sheldon Jackson	1F1NW113 4110190	Alaska and Yukon	SE Alaska	SE Alaska	Baranof Island
AKY-17	Medvejie	1F1NW113 41	Alaska and Yukon	SE Alaska	SE Alaska	Baranof Island
AKY-18	Port Armstrong	1F1NE109 10	Alaska and Yukon	SE Alaska	SE Alaska	Baranof Island
AKY-19	Little Port Walter	1F1NE109 1099999	Alaska and Yukon	SE Alaska	SE Alaska	Baranof Island
AKY-20	Hidden Falls	1F1NE112 1110110	Alaska and Yukon	SE Alaska	SE Alaska	Baranof Island
AKY-21	Crystal Lake	1F1SE106 4410310	Alaska and Yukon	SE Alaska	SE Alaska	Mitkof and Pr of Wales
AKY-22	Klawock	1F1SW103 6010470	Alaska and Yukon	SE Alaska	SE Alaska	Mitkof and Pr of Wales
AKY-23	Neets Bay	1F1SE101 9010100	Alaska and Yukon	SE Alaska	SE Alaska	Ketchikan Area
AKY-24	Deer Mountain	1F1SE101 4710250	Alaska and Yukon	SE Alaska	SE Alaska	Ketchikan Area
AKY-25	Whitman Lake	1F1SE101 4510070	Alaska and Yukon	SE Alaska	SE Alaska	Ketchikan Area
AKY-26	Tamgas Creek	1F1SE101 2510250	Alaska and Yukon	SE Alaska	SE Alaska	Ketchikan Area
BCP-01	Masset	2FN QCI H0121	BC and Puget Sound	Coastal BC	Northern BC	Qn Charlotte Islands
BCP-02	Coates Creek	2FN QCI H1921	BC and Puget Sound	Coastal BC	Northern BC	Qn Charlotte Islands
BCP-03	Pallant Creek	2FN QCI H0148	BC and Puget Sound	Coastal BC	Northern BC	Qn Charlotte Islands
BCP-04	Sewell Inlet	2FN QCI H0173	BC and Puget Sound	Coastal BC	Northern BC	Qn Charlotte Islands
BCP-05	Kincolith	2FN NASSH0120	BC and Puget Sound	Coastal BC	Northern BC	Nass and Skeena
BCP-06	Terrace	2FN SKNAH0340	BC and Puget Sound	Coastal BC	Northern BC	Nass and Skeena

Label	Hatchery	Hatchery Code	Domain	Realm	Area	Locality
BCP-07	Kispiox River	2FN SKNAH0119	BC and Puget Sound	Coastal BC	Northern BC	Nass and Skeena
BCP-08	Toboggan Creek	2FN SKNAH0839	BC and Puget Sound	Coastal BC	Northern BC	Nass and Skeena
BCP-09	Fort Babine	2FN SKNAH0597	BC and Puget Sound	Coastal BC	Northern BC	Nass and Skeena
BCP-10	Hartley Bay	2FN CCSTH0308	BC and Puget Sound	Coastal BC	Northern BC	Douglas Channel
BCP-11	Kitimat River	2FN CCSTH0146	BC and Puget Sound	Coastal BC	Northern BC	Douglas Channel
BCP-12	Klemtu	2FN CCSTH0406	BC and Puget Sound	Coastal BC	Central BC	Qn Charlotte Sound
BCP-13	Bella Bella	2FN CCSTH0123	BC and Puget Sound	Coastal BC	Central BC	Qn Charlotte Sound
BCP-14	Snootli Creek	2FN CCSTH0140	BC and Puget Sound	Coastal BC	Central BC	Qn Charlotte Sound
BCP-15	Shotbolt Bay	2FN RIVRH2244	BC and Puget Sound	Coastal BC	Central BC	Qn Charlotte Sound
BCP-16	Oweekeno	2FN RIVRH0438	BC and Puget Sound	Coastal BC	Central BC	Qn Charlotte Sound
BCP-17	Quatse	2FS JNSTH0783	BC and Puget Sound	Coastal BC	Central BC	Qn Charlotte Sound
BCP-18	Nimpkish	2FS JNSTH0122	BC and Puget Sound	Coastal BC	Central BC	Qn Charlotte Sound
BCP-19	Marble River	2FS NWVIH0351	BC and Puget Sound	Coastal BC	W Vancouver Island	NW Vancouver Island
BCP-20	Conuma River	2FS NWVIH0117	BC and Puget Sound	Coastal BC	W Vancouver Island	NW Vancouver Island
BCP-21	Gold River	2FS NWVIH0030	BC and Puget Sound	Coastal BC	W Vancouver Island	NW Vancouver Island
BCP-22	Clayoquot	2FS SWVIH1037	BC and Puget Sound	Coastal BC	W Vancouver Island	SW Vancouver Island
BCP-23	Robertson Creek	2FS SWVIH0104	BC and Puget Sound	Coastal BC	W Vancouver Island	SW Vancouver Island
BCP-24	Nitinat	2FS SWVIH0114	BC and Puget Sound	Coastal BC	W Vancouver Island	SW Vancouver Island
BCP-25	San Juan River	2FS SWVIH0093	BC and Puget Sound	Coastal BC	W Vancouver Island	SW Vancouver Island
BCP-26	Sooke River	2FS SWVIH0490	BC and Puget Sound	Coastal BC	W Vancouver Island	SW Vancouver Island
BCP-27	Quinsam River	2FS JNSTH0106	BC and Puget Sound	Georgia Strait	E Vancouver Island	E Vancouver Island
BCP-28	Oyster River	2FS GSVIH0277	BC and Puget Sound	Georgia Strait	E Vancouver Island	E Vancouver Island
BCP-29	Puntledge River	2FS GSVIH0105	BC and Puget Sound	Georgia Strait	E Vancouver Island	E Vancouver Island
BCP-30	Rosewall Creek	2FS GSVIH0111	BC and Puget Sound	Georgia Strait	E Vancouver Island	E Vancouver Island
BCP-31	Big Qualicum River	2FS GSVIH0100	BC and Puget Sound	Georgia Strait	E Vancouver Island	E Vancouver Island
BCP-32	Little Qualicum River	2FS GSVIH0102	BC and Puget Sound	Georgia Strait	E Vancouver Island	E Vancouver Island
BCP-33	Englishman River	2FS GSVIH0213	BC and Puget Sound	Georgia Strait	E Vancouver Island	E Vancouver Island
BCP-34	Pacific Bio Station	2FS GSVIH0192	BC and Puget Sound	Georgia Strait	E Vancouver Island	SE Vancouver Island
BCP-35	Millstone River	2FS GSVIH2269	BC and Puget Sound	Georgia Strait	E Vancouver Island	SE Vancouver Island
BCP-36	Malaspina College	2FS GSVIH1933	BC and Puget Sound	Georgia Strait	E Vancouver Island	SE Vancouver Island
BCP-37	Nanaimo River	2FS GSVIH0126	BC and Puget Sound	Georgia Strait	E Vancouver Island	SE Vancouver Island
BCP-38	Chemainus River	2FS GSVIH0151	BC and Puget Sound	Georgia Strait	E Vancouver Island	SE Vancouver Island
BCP-39	Cowichan River	2FS GSVIH0118	BC and Puget Sound	Georgia Strait	E Vancouver Island	SE Vancouver Island
BCP-40	Goldstream River	2FS GSVIH0295	BC and Puget Sound	Georgia Strait	E Vancouver Island	SE Vancouver Island
BCP-41	Sliammon River	2FS GSMNH0124	BC and Puget Sound	Georgia Strait	Southern BC coast	Malaspina Strait
BCP-42	Powell River	2FS GSMNH0443	BC and Puget Sound	Georgia Strait	Southern BC coast	Malaspina Strait
BCP-43	Vancouver Bay	2FS GSMNH0049	BC and Puget Sound	Georgia Strait	Southern BC coast	Malaspina Strait
BCP-44	Sechelt	2FS GSMNH0125	BC and Puget Sound	Georgia Strait	Southern BC coast	Malaspina Strait
BCP-45	Tenderfoot Creek	2FS GSMNH0153	BC and Puget Sound	Georgia Strait	Southern BC coast	Burrard and Howe
BCP-46	Capilano River	2FS GSMNH0103	BC and Puget Sound	Georgia Strait	Southern BC coast	Burrard and Howe

Label	Hatchery	Hatchery Code	Domain	Realm	Area	Locality
BCP-47	Seymour River	2FS GSMNH0112	BC and Puget Sound	Georgia Strait	Southern BC coast	Burrard and Howe
BCP-48	Inch Creek	2FS LWFRH0150	BC and Puget Sound	Georgia Strait	Fraser Basin	Lower Fraser
BCP-49	Chehalis River	2FS LWFRH0154	BC and Puget Sound	Georgia Strait	Fraser Basin	Lower Fraser
BCP-50	Chilliwack River	2FS LWFRH0107	BC and Puget Sound	Georgia Strait	Fraser Basin	Lower Fraser
BCP-51	Birkenhead River	2FS UPFRH0152	BC and Puget Sound	Georgia Strait	Fraser Basin	Birkenhead River
BCP-52	Spius Creek	2FS TOMMH0160	BC and Puget Sound	Georgia Strait	Fraser Basin	Thompson River
BCP-53	Loon Creek	2FS TOMMH0157	BC and Puget Sound	Georgia Strait	Fraser Basin	Thompson River
BCP-54	Thompson River	2FS TOMFH0188	BC and Puget Sound	Georgia Strait	Fraser Basin	Thompson River
BCP-55	Clearwater River	2FS TOMFH0162	BC and Puget Sound	Georgia Strait	Fraser Basin	Thompson River
BCP-56	Shuswap River	2FS TOMFH0048	BC and Puget Sound	Georgia Strait	Fraser Basin	Thompson River
BCP-57	Eagle River	2FS TOMFH0156	BC and Puget Sound	Georgia Strait	Fraser Basin	Thompson River
BCP-58	Quesnel River	2FS UPFRH0155	BC and Puget Sound	Georgia Strait	Fraser Basin	Upper Fraser
BCP-59	Fort St. James	2FS UPFRH0410	BC and Puget Sound	Georgia Strait	Fraser Basin	Upper Fraser
BCP-60	Penny	2FS UPFRH0270	BC and Puget Sound	Georgia Strait	Fraser Basin	Upper Fraser
BCP-61	Kendall Creek	3F10107 010406 H	BC and Puget Sound	Puget Sound	Outer Puget Sound	NE Puget Sound
BCP-62	Skookum Creek	3F10107 010273 H	BC and Puget Sound	Puget Sound	Outer Puget Sound	NE Puget Sound
BCP-63	Samish	3F10107 030017 H	BC and Puget Sound	Puget Sound	Outer Puget Sound	NE Puget Sound
BCP-64	PSE Spawning	3F10208 030435 H	BC and Puget Sound	Puget Sound	Outer Puget Sound	E Puget Sound
BCP-65	Marblemount	3F10208 031421 H	BC and Puget Sound	Puget Sound	Outer Puget Sound	E Puget Sound
BCP-66	Stillaguamish	3F10308 050126 H	BC and Puget Sound	Puget Sound	Outer Puget Sound	E Puget Sound
BCP-67	Tulalip	3F10308 070001 H	BC and Puget Sound	Puget Sound	Outer Puget Sound	E Puget Sound
BCP-68	Wallace River	3F10308 070943 H	BC and Puget Sound	Puget Sound	Outer Puget Sound	E Puget Sound
BCP-69	Snoqualmie River	3F10308 070219 H84	BC and Puget Sound	Puget Sound	Outer Puget Sound	E Puget Sound
BCP-70	Grovers Creek	3F10510 150299 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	SE Puget Sound
BCP-71	Portage Bay	3F10510 080028 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	SE Puget Sound
BCP-72	Seward Park	3F10510 080028AH01	BC and Puget Sound	Puget Sound	Inner Puget Sound	SE Puget Sound
BCP-73	Issaquah	3F10510 080178 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	SE Puget Sound
BCP-74	Soos Creek	3F10510 090072 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	SE Puget Sound
BCP-75	Crisp Creek	3F10510 090113 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	SE Puget Sound
BCP-76	White River	3F10511 100031 H01	BC and Puget Sound	Puget Sound	Inner Puget Sound	SE Puget Sound
BCP-77	Voights Creek	3F10511 100414 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	SE Puget Sound
BCP-78	Minter Creek	3F10513 150048 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	S Puget Sound
BCP-79	Hupp Springs	3F10513 150048 H02	BC and Puget Sound	Puget Sound	Inner Puget Sound	S Puget Sound
BCP-80	Garrison Springs	3F10513 120007 H01	BC and Puget Sound	Puget Sound	Inner Puget Sound	S Puget Sound
BCP-81	Kalama Creek	3F10513 110017AH	BC and Puget Sound	Puget Sound	Inner Puget Sound	S Puget Sound
BCP-82	Capitol Lake	3F10513 130028 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	S Puget Sound
BCP-83	Big Beef Creek	3F10412 150389 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	Hood Canal
BCP-84	Quilcene	3F10412 170012 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	Hood Canal
BCP-85	Hoodsport	3F10412 160222 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	Hood Canal
BCP-86	George Adams	3F10412 160005 H	BC and Puget Sound	Puget Sound	Inner Puget Sound	Hood Canal

Label	Hatchery	Hatchery Code	Domain	Realm	Area	Locality
WOC-01	Dungeness	3F10806 180018 H	Coastal WaOrCa	Coastal Washington	Olympic Peninsula	N Olympic Peninsula
WOC-02	Lower Elwha	3F10806 180274 H	Coastal WaOrCa	Coastal Washington	Olympic Peninsula	N Olympic Peninsula
WOC-03	Makah	3F21704 200015 H	Coastal WaOrCa	Coastal Washington	Olympic Peninsula	N Olympic Peninsula
WOC-04	Solduc	3F21703 200096 H02	Coastal WaOrCa	Coastal Washington	Olympic Peninsula	S Olympic Peninsula
WOC-05	Chalaat Creek	3F21703 200423 H	Coastal WaOrCa	Coastal Washington	Olympic Peninsula	S Olympic Peninsula
WOC-06	Salmon River (WA)	3F21703 210139 H	Coastal WaOrCa	Coastal Washington	Olympic Peninsula	S Olympic Peninsula
WOC-07	Quinault	3F21702 210429 H	Coastal WaOrCa	Coastal Washington	Olympic Peninsula	S Olympic Peninsula
WOC-08	Quinault Lake	3F21702 210398 H	Coastal WaOrCa	Coastal Washington	Olympic Peninsula	S Olympic Peninsula
WOC-09	Humptulips	3F21802 220004 H	Coastal WaOrCa	Coastal Washington	Grays and Willapa	Grays Harbor
WOC-10	Bingham Creek	3F21802 220360 H	Coastal WaOrCa	Coastal Washington	Grays and Willapa	Grays Harbor
WOC-11	Forks Creek	3F21902 240356 H	Coastal WaOrCa	Coastal Washington	Grays and Willapa	Willapa Bay
WOC-12	Nemah	3F21902 240460 H	Coastal WaOrCa	Coastal Washington	Grays and Willapa	Willapa Bay
WOC-13	Naselle	3F21902 240543 H	Coastal WaOrCa	Coastal Washington	Grays and Willapa	Willapa Bay
WOC-14	Nehalem	5F22218 H18 21	Coastal WaOrCa	Coastal Oregon	N Oregon coast	N Oregon coast
WOC-15	Trask	5F22229 H29 21	Coastal WaOrCa	Coastal Oregon	N Oregon coast	N Oregon coast
WOC-16	Cedar Creek	5F22206 H6 21	Coastal WaOrCa	Coastal Oregon	N Oregon coast	N Oregon coast
WOC-17	Salmon River (OR)	5F22225 H25 21	Coastal WaOrCa	Coastal Oregon	N Oregon coast	Salmon and Siletz
WOC-18	Siletz	5F22227 H27 21	Coastal WaOrCa	Coastal Oregon	N Oregon coast	Salmon and Siletz
WOC-19	Yaquina Bay	5F22101 H1 23	Coastal WaOrCa	Coastal Oregon	N Oregon coast	Yaquina Bay
WOC-20	Wright Creek	5F22106 H6 23	Coastal WaOrCa	Coastal Oregon	N Oregon coast	Yaquina Bay
WOC-21	Fall Creek	5F22210 H10 21	Coastal WaOrCa	Coastal Oregon	S Oregon coast	C Oregon coast
WOC-22	Rock Creek	5F22223 H23 21	Coastal WaOrCa	Coastal Oregon	S Oregon coast	C Oregon coast
WOC-23	Coos Bay (Anad Inc)	5F22103 H3 23	Coastal WaOrCa	Coastal Oregon	S Oregon coast	Coos Bay
WOC-24	Domsea Farms	5F22104 H4 23	Coastal WaOrCa	Coastal Oregon	S Oregon coast	Coos Bay
WOC-25	Coos Bay (Oreg Aqua)	5F22102 H2 23	Coastal WaOrCa	Coastal Oregon	S Oregon coast	Coos Bay
WOC-26	Bandon	5F22237 H37 21	Coastal WaOrCa	Coastal Oregon	S Oregon coast	S Oregon coast
WOC-27	Elk River	5F22209 H9 21	Coastal WaOrCa	Coastal Oregon	S Oregon coast	S Oregon coast
WOC-28	Indian Creek	5F22241 H41 21	Coastal WaOrCa	Coastal Oregon	S Oregon coast	S Oregon coast
WOC-29	Cole Rivers	5F22208 H8 21	Coastal WaOrCa	Coastal Oregon	S Oregon coast	S Oregon coast
WOC-30	Butte Falls	5F22204 H4 21	Coastal WaOrCa	Coastal Oregon	S Oregon coast	S Oregon coast
WOC-31	Burnt Hill Creek	5F22107 H7 23	Coastal WaOrCa	Coastal Oregon	S Oregon coast	S Oregon coast
WOC-32	Iron Gate	6FKKLUPR IRGH	Coastal WaOrCa	California	N California coast	N California coast
WOC-33	Trinity River	6FKTRUTR TRHA	Coastal WaOrCa	California	N California coast	N California coast
WOC-34	Mad River	6FBMAMAD MRFH	Coastal WaOrCa	California	N California coast	N California coast
WOC-35	Warm Springs (CA)	6FBRRDRC WSFH	Coastal WaOrCa	California	N California coast	N California coast
WOC-36	Nimbus	6FCSAAMN NBFH	Coastal WaOrCa	California	San Francisco Bay	Sacramento River
WOC-37	Feather River	6FCSAFEA FRFH	Coastal WaOrCa	California	San Francisco Bay	Sacramento River
WOC-38	Tehama-Colusa	6FCSACOY TCFF	Coastal WaOrCa	California	San Francisco Bay	Sacramento River
WOC-39	Coleman	6FCSABAT CNFH	Coastal WaOrCa	California	San Francisco Bay	Sacramento River
WOC-40	Mokelumne River	6FCSJMOK MRFI	Coastal WaOrCa	California	San Francisco Bay	San Joaquin River

Label	Hatchery	Hatchery Code	Domain	Realm	Area	Locality
WOC-41	Merced River	6FCSJMER MRFF	Coastal WaOrCa	California	San Francisco Bay	San Joaquin River
COL-01	Vanderveldt	5F33208 H8 22	Columbia Basin	Columbia Basin	Columbia below dams	Columbia mouth
COL-02	Klaskanine	5F33214 H14 21	Columbia Basin	Columbia Basin	Columbia below dams	Columbia mouth
COL-03	Big Creek	5F33202 H2 21	Columbia Basin	Columbia Basin	Columbia below dams	Columbia mouth
COL-04	Grays River	3F42001 250131 H	Columbia Basin	Columbia Basin	Columbia below dams	Columbia mouth
COL-05	Elochoman	3F42001 250236 H	Columbia Basin	Columbia Basin	Columbia below dams	Columbia mouth
COL-06	Abernathy	3F42001 250297 H	Columbia Basin	Columbia Basin	Columbia below dams	Columbia mouth
COL-07	Cowlitz	3F42001 260002 H02	Columbia Basin	Columbia Basin	Columbia below dams	First Columbia tribs
COL-08	North Toutle	3F42001 260323 H	Columbia Basin	Columbia Basin	Columbia below dams	First Columbia tribs
COL-09	Fallert Creek	3F42001 270017 H	Columbia Basin	Columbia Basin	Columbia below dams	First Columbia tribs
COL-10	Kalama Falls	3F42001 270002 H	Columbia Basin	Columbia Basin	Columbia below dams	First Columbia tribs
COL-11	Lewis River	3F42001 270168 H	Columbia Basin	Columbia Basin	Columbia below dams	First Columbia tribs
COL-12	Clackamas	5F33307 H7 21	Columbia Basin	Columbia Basin	Columbia below dams	Willamette River
COL-13	Eagle Creek	5F33301 H1 22	Columbia Basin	Columbia Basin	Columbia below dams	Willamette River
COL-14	Stayton	5F33333 H33 21	Columbia Basin	Columbia Basin	Columbia below dams	Willamette River
COL-15	Marion Forks	5F33316 H16 21	Columbia Basin	Columbia Basin	Columbia below dams	Willamette River
COL-16	South Santiam	5F33328 H28 21	Columbia Basin	Columbia Basin	Columbia below dams	Willamette River
COL-17	McKenzie	5F33317 H17 21	Columbia Basin	Columbia Basin	Columbia below dams	Willamette River
COL-18	Dexter	5F33334 H34 21	Columbia Basin	Columbia Basin	Columbia below dams	Willamette River
COL-19	Willamette	5F33319 H19 21	Columbia Basin	Columbia Basin	Columbia below dams	Willamette River
COL-20	Sandy River	5F33226 H26 21	Columbia Basin	Columbia Basin	Columbia below dams	Bonneville below dam
COL-21	Washougal	3F42001 280159 H	Columbia Basin	Columbia Basin	Columbia below dams	Bonneville below dam
COL-22	Wahkeena	5F33236 H36 21	Columbia Basin	Columbia Basin	Columbia below dams	Bonneville below dam
COL-23	Bonneville	5F33201 H1 21	Columbia Basin	Columbia Basin	Columbia below dams	Bonneville below dam
COL-24	Cascade	5F33405 H5 21	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-25	Oxbow	5F33421 H21 21	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-26	Carson	3F42001 290023 H	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-27	Little White Salmon	3F42001 290131 H02	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-28	Willard	3F42001 290131 H03	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-29	Spring Creek	3F42001 290159 H	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-30	Klickitat	3F42001 300002 H	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-31	Warm Springs (OR)	5F33407 H7 22	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-32	Round Butte	5F33424 H24 21	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-33	Umatilla	5F33449 H49 21	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-34	Yakima	3F42001 371381 H	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-35	Ringold Springs	3F42001 360001 H04	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-36	Priest Rapids	3F42001 360126 H	Columbia Basin	Columbia Basin	Columbia above dams	Mid Columbia
COL-37	Dryden Pond	3F42001 450030 H	Columbia Basin	Columbia Basin	Columbia above dams	Upper Columbia
COL-38	Leavenworth	3F42001 450474 H	Columbia Basin	Columbia Basin	Columbia above dams	Upper Columbia
COL-39	Chiwawa	3F42001 450759 H	Columbia Basin	Columbia Basin	Columbia above dams	Upper Columbia

Label	Hatchery	Hatchery Code	Domain	Realm	Area	Locality
COL-40	Turtle Rock	3F42001 440001 H04	Columbia Basin	Columbia Basin	Columbia above dams	Upper Columbia
COL-41	Entiat	3F42001 460042 H	Columbia Basin	Columbia Basin	Columbia above dams	Upper Columbia
COL-42	Wells Dam	3F42001 470001 H	Columbia Basin	Columbia Basin	Columbia above dams	Upper Columbia
COL-43	Winthrop	3F42001 480002 H	Columbia Basin	Columbia Basin	Columbia above dams	Upper Columbia
COL-44	Methow	3F42001 480002 H03	Columbia Basin	Columbia Basin	Columbia above dams	Upper Columbia
COL-45	Similkameen	3F42001 490325 H01	Columbia Basin	Columbia Basin	Columbia above dams	Upper Columbia
COL-46	Lyons Ferry	3F42001 330002 H01	Columbia Basin	Columbia Basin	Snake River	Lower Snake
COL-47	Hagerman	4F-1704021205605.50	Columbia Basin	Columbia Basin	Snake River	Upper Snake
COL-48	Dworshak	4F-1706030800100.10	Columbia Basin	Columbia Basin	Snake River	Upper Snake
COL-49	Kooskia	4F-1706030400200.50	Columbia Basin	Columbia Basin	Snake River	Upper Snake
COL-50	Lookingglass	5F33539 H39 21	Columbia Basin	Columbia Basin	Snake River	Upper Snake
COL-51	Rapid River	4F-1706021000203.70	Columbia Basin	Columbia Basin	Snake River	Upper Snake
COL-52	McCall	4F-1705012303330.00	Columbia Basin	Columbia Basin	Snake River	Upper Snake
COL-53	Sawtooth	4F-1706020106901.25	Columbia Basin	Columbia Basin	Snake River	Upper Snake

Notes:
Numbers in the Label field correspond to the hatchery labels in Figures 3 through 7.
In the Domain field, “Coastal WaOrCa” is used as shorthand for Coastal Washington, Oregon, and California.

Appendix B

List of Hatcheries, with Salmon Release and Survival Information

Label	Hatchery	Coho Grps	Coho Surv	Fall chinook Grps	Fall chinook Surv	Spring chinook Grps	Spring chinook Surv
AKY-01	Klondike River					15	0.00%
AKY-02	McIntyre Creek					30	0.00%
AKY-03	Whitehorse					42	0.16%
AKY-04	Crooked Creek	10	0.13%				
AKY-05	Trail Lakes	30	0.13%				
AKY-06	Elmendorf	56	0.56%			45	0.17%
AKY-07	Fort Richardson	48	1.14%			35	0.27%
AKY-08	Big Lake	29	0.33%				
AKY-09	Wally Noerenberg	16	2.01%			10	0.42%
AKY-10	Solomon Gulch	15	1.11%				
AKY-11	Jerry Myers					10	0.52%
AKY-12	Auke Creek	16	4.13%				
AKY-13	Gastineau	50	8.53%			18	0.90%
AKY-14	Snettisham	41	2.76%			118	0.50%
AKY-15	Starrigavan	34	0.33%				
AKY-16	Sheldon Jackson	57	2.16%			21	0.81%
AKY-17	Medvejie	66	8.41%			73	2.32%
AKY-18	Port Armstrong	20	9.89%				
AKY-19	Little Port Walter	74	3.46%			402	2.85%
AKY-20	Hidden Falls	30	10.42%			89	1.24%
AKY-21	Crystal Lake	86	1.94%			81	1.17%
AKY-22	Klawock	88	3.51%				
AKY-23	Neets Bay	103	6.53%			59	0.81%
AKY-24	Deer Mountain	98	4.73%			96	1.10%
AKY-25	Whitman Lake	61	6.44%			30	3.60%
AKY-26	Tamgas Creek	52	3.05%			25	0.31%
BCP-01	Masset	22	1.06%	30	0.24%		
BCP-02	Coates Creek	10	1.53%				
BCP-03	Pallant Creek	97	2.25%				
BCP-04	Sewell Inlet	11	4.86%				
BCP-05	Kincolith	25	1.00%			21	0.67%
BCP-06	Terrace	12	1.07%	94	0.19%	12	0.11%
BCP-07	Kispiox River	25	1.80%				
BCP-08	Toboggan Creek	60	1.39%			21	0.30%
BCP-09	Fort Babine	43	1.63%			20	0.94%
BCP-10	Hartley Bay	55	1.50%				
BCP-11	Kitimat River	51	2.12%	88	0.61%		
BCP-12	Klemtu	17	2.85%				
BCP-13	Bella Bella	35	4.19%				
BCP-14	Snootli Creek	26	2.41%	88	0.40%		
BCP-15	Shotbolt Bay			17	0.15%		
BCP-16	Oweekeno			22	0.38%		
BCP-17	Quatse	14	2.14%				
BCP-18	Nimpkish			13	0.21%		
BCP-19	Marble River			16	0.92%		
BCP-20	Conuma River	22	4.16%	60	1.72%		

Label	Hatchery	Coho Grps	Coho Surv	Fall chinook Grps	Fall chinook Surv	Spring chinook Grps	Spring chinook Surv
BCP-21	Gold River			18	0.97%		
BCP-22	Clayoquot			10	1.82%		
BCP-23	Robertson Creek	53	4.34%	235	1.98%		
BCP-24	Nitinat	18	2.37%	82	0.86%		
BCP-25	San Juan River	22	1.97%	21	0.49%		
BCP-26	Sooke River			12	0.30%		
BCP-27	Quinsam River	247	6.04%	263	0.92%		
BCP-28	Oyster River			10	0.15%		
BCP-29	Puntledge River	138	2.92%	127	0.39%		
BCP-30	Rosewall Creek	118	12.99%				
BCP-31	Big Qualicum River	120	7.92%	169	0.79%		
BCP-32	Little Qualicum River			42	0.43%		
BCP-33	Englishman River			15	0.25%		
BCP-34	Pacific Bio Station	11	1.30%				
BCP-35	Millstone River	11	1.09%				
BCP-36	Malaspina College	13	5.22%				
BCP-37	Nanaimo River	21	3.17%	42	0.79%		
BCP-38	Chemainus River			44	2.30%		
BCP-39	Cowichan River			91	0.94%		
BCP-40	Goldstream River			16	0.93%		
BCP-41	Sliammon River	27	2.82%				
BCP-42	Powell River	19	2.07%	10	0.35%		
BCP-43	Vancouver Bay	11	2.22%				
BCP-44	Sechelt	19	5.27%	20	0.05%	11	0.91%
BCP-45	Tenderfoot Creek	59	6.08%	84	0.41%		
BCP-46	Capilano River	223	9.50%	157	0.46%		
BCP-47	Seymour River			13	0.26%		
BCP-48	Inch Creek	85	5.66%	12	0.01%		
BCP-49	Chehalis River	54	7.95%	69	0.80%		
BCP-50	Chilliwack River	94	9.67%	68	1.49%		
BCP-51	Birkenhead River			31	0.07%		
BCP-52	Spius Creek	42	1.34%	60	0.26%	40	0.47%
BCP-53	Loon Creek			13	0.21%		
BCP-54	Thompson River	70	2.92%				
BCP-55	Clearwater River			77	0.25%		
BCP-56	Shuswap River			46	0.66%		
BCP-57	Eagle River	93	1.23%	79	0.18%	17	0.15%
BCP-58	Quesnel River			207	0.06%		
BCP-59	Fort St. James			24	0.09%		
BCP-60	Penny					27	0.31%
BCP-61	Kendall Creek	30	9.86%	21	2.05%	19	0.66%
BCP-62	Skookum Creek	29	9.91%	22	0.77%		
BCP-63	Samish			21	1.59%		
BCP-64	PSE Spawning	13	4.83%				
BCP-65	Marblemount	59	8.73%	16	0.51%	25	1.50%
BCP-66	Stillaguamish			17	0.56%		
BCP-67	Tulalip	25	8.27%				
BCP-68	Wallace River	27	11.19%				
BCP-69	Snoqualmie River	12	2.50%				
BCP-70	Grovers Creek			92	0.75%		
BCP-71	Portage Bay	25	3.59%	73	2.52%		
BCP-72	Seward Park	10	0.35%				
BCP-73	Issaquah	10	8.35%	13	0.78%		
BCP-74	Soos Creek	126	7.70%	40	0.70%		
BCP-75	Crisp Creek	13	2.55%				
BCP-76	White River			13	0.18%		

Label	Hatchery	Coho		Fall chinook		Spring chinook	
		Grps	Surv	Grps	Surv	Grps	Surv
BCP-77	Voights Creek	75	9.24%				
BCP-78	Minter Creek	44	6.30%	16	0.37%	15	0.61%
BCP-79	Hupp Springs			20	0.26%	27	1.01%
BCP-80	Garrison Springs	19	3.36%	22	0.26%		
BCP-81	Kalama Creek	13	3.27%	22	0.43%		
BCP-82	Capitol Lake					20	2.82%
BCP-83	Big Beef Creek			12	2.61%		
BCP-84	Quilcene	49	4.17%			57	0.06%
BCP-85	Hoodsport			22	0.52%	45	1.24%
BCP-86	George Adams	36	5.58%	29	0.47%		
WOC-01	Dungeness	50	4.19%				
WOC-02	Lower Elwha	28	1.28%	31	0.31%	21	0.88%
WOC-03	Makah	43	3.66%	46	0.26%		
WOC-04	Solduc	115	1.42%	25	0.37%	24	1.68%
WOC-05	Chalaat Creek	13	1.03%				
WOC-06	Salmon River (WA)	46	1.00%	11	0.70%		
WOC-07	Quinault	54	1.30%	55	0.81%		
WOC-08	Quinault Lake	53	1.15%	43	0.71%		
WOC-09	Humptulips	62	2.20%	10	1.23%		
WOC-10	Bingham Creek	61	1.55%	14	0.51%		
WOC-11	Forks Creek	26	2.87%	17	1.13%		
WOC-12	Nemah			18	1.06%		
WOC-13	Naselle	10	5.96%				
WOC-14	Nehalem	52	1.26%				
WOC-15	Trask	53	1.31%	139	0.75%		
WOC-16	Cedar Creek			17	0.62%		
WOC-17	Salmon River (OR)	50	0.81%	59	2.28%		
WOC-18	Siletz	30	1.27%				
WOC-19	Yaquina Bay	628	0.75%	85	1.14%		
WOC-20	Wright Creek	59	0.38%				
WOC-21	Fall Creek	122	1.09%	14	0.90%		
WOC-22	Rock Creek	37	1.47%	33	0.56%	16	1.18%
WOC-23	Coos Bay (Anad Inc)	239	1.91%	135	1.07%	10	0.48%
WOC-24	Domsea Farms	13	0.95%	10	0.35%		
WOC-25	Coos Bay (Oreg Aqua)	22	0.73%				
WOC-26	Bandon	12	0.72%	10	0.25%		
WOC-27	Elk River			146	1.82%		
WOC-28	Indian Creek			14	0.53%		
WOC-29	Cole Rivers	59	2.77%	280	2.23%		
WOC-30	Butte Falls	54	1.76%	15	0.99%		
WOC-31	Burnt Hill Creek			19	0.92%		
WOC-32	Iron Gate	27	1.24%	75	0.57%		
WOC-33	Trinity River	35	1.16%	105	0.75%		
WOC-34	Mad River	12	1.10%	11	0.33%		
WOC-35	Warm Springs (CA)	45	0.09%				
WOC-36	Nimbus			23	2.32%		
WOC-37	Feather River			337	0.91%		
WOC-38	Tehama-Colusa			28	1.61%		
WOC-39	Coleman			295	0.44%		
WOC-40	Mokelumne River			80	0.97%		
WOC-41	Merced River			127	0.70%		
COL-01	Vanderveldt	15	1.59%				
COL-02	Klaskanine	55	2.45%	58	1.15%		
COL-03	Big Creek	305	1.54%	171	1.45%		
COL-04	Grays River	43	1.40%	44	1.13%		
COL-05	Elochoman	40	1.21%	28	0.38%		

Label	Hatchery	Coho Grps	Coho Surv	Fall chinook Grps	Fall chinook Surv	Spring chinook Grps	Spring chinook Surv
COL-06	Abernathy			392	0.60%		
COL-07	Cowlitz	140	2.08%	67	0.60%	126	2.36%
COL-08	North Toutle	34	2.42%	20	0.50%		
COL-09	Fallert Creek	13	1.29%	17	0.84%		
COL-10	Kalama Falls	23	3.24%	22	0.62%		
COL-11	Lewis River	34	2.13%	13	1.35%	14	0.50%
COL-12	Clackamas			27	0.22%	19	1.05%
COL-13	Eagle Creek	68	1.38%			23	0.72%
COL-14	Stayton			81	0.44%		
COL-15	Marion Forks			15	0.24%	64	0.62%
COL-16	South Santiam			31	0.95%	22	0.93%
COL-17	McKenzie			42	0.46%	64	0.55%
COL-18	Dexter			11	1.17%	17	0.63%
COL-19	Willamette			50	0.83%	105	0.91%
COL-20	Sandy River	178	3.42%				
COL-21	Washougal	146	1.53%	49	1.14%		
COL-22	Wahkeena	26	1.24%				
COL-23	Bonneville	34	1.92%	419	0.44%	82	0.88%
COL-24	Cascade	103	1.41%				
COL-25	Oxbow	23	3.16%				
COL-26	Carson					148	0.26%
COL-27	Little White Salmon			136	0.25%	36	0.22%
COL-28	Willard	70	0.51%				
COL-29	Spring Creek			289	0.48%		
COL-30	Klickitat	31	1.21%	31	0.24%	61	0.39%
COL-31	Warm Springs (OR)					143	0.10%
COL-32	Round Butte			30	0.16%	68	0.74%
COL-33	Umatilla			148	0.14%	29	0.17%
COL-34	Yakima			15	0.06%		
COL-35	Ringold Springs			10	0.76%		
COL-36	Priest Rapids			45	0.88%		
COL-37	Dryden Pond					11	0.15%
COL-38	Leavenworth			29	0.02%	111	0.11%
COL-39	Chiwawa					11	0.09%
COL-40	Turtle Rock					12	0.96%
COL-41	Entiat			11	0.01%	28	0.05%
COL-42	Wells Dam			31	0.09%	18	0.35%
COL-43	Winthrop					39	0.04%
COL-44	Methow					36	0.06%
COL-45	Similkameen					12	0.65%
COL-46	Lyons Ferry			35	0.25%	76	0.64%
COL-47	Hagerman			15	0.57%		
COL-48	Dworshak			17	0.04%	108	0.04%
COL-49	Kooskia					41	0.04%
COL-50	Lookingglass			38	0.04%	118	0.11%
COL-51	Rapid River					80	0.06%
COL-52	McCall					74	0.08%
COL-53	Sawtooth			27	0.00%	80	0.03%

Notes:
Numbers in the Label field correspond to the hatchery labels in Figures 3 through 7.
In the table headings, “Grps” is used as shorthand for the number of CWT groups released, and “Surv” is used as shorthand for the average survival rate of these groups.

Appendix C

List of Hatcheries in Fraser and Columbia Basins, with Information about Segments, Dams, and Distance Upstream

Label	Hatchery	Upstream (km)	Dams	Fraser Segment	Coho Surv	Fall Surv	Spring Surv
BCP-48	Inch Creek	80	0	Lower Fraser	5.66%	0.01%	
BCP-49	Chehalis River	97	0	Lower Fraser	7.95%	0.80%	
BCP-50	Chilliwack River	111	0	Lower Fraser	9.67%	1.49%	
BCP-51	Birkenhead River	296	0	Lower Fraser		0.07%	
BCP-52	Spius Creek	370	0	Thompson River	1.34%	0.26%	0.47%
BCP-53	Loon Creek	378	0	Thompson River		0.21%	
BCP-54	Thompson River	423	0	Thompson River	2.92%		
BCP-55	Clearwater River	444	0	Thompson River		0.25%	
BCP-56	Shuswap River	592	0	Thompson River		0.66%	
BCP-57	Eagle River	650	0	Thompson River	1.23%	0.18%	0.15%
BCP-58	Quesnel River	629	0	Upper Fraser		0.06%	
BCP-59	Fort St. James	772	0	Upper Fraser		0.09%	
BCP-60	Penny	777	0	Upper Fraser			0.31%

Label	Hatchery	Upstream (km)	Dams	Columbia Segment	Coho Surv	Fall Surv	Spring Surv
COL-1	Vanderveldt	16	0	Columbia below dams	1.59%		
COL-2	Klaskanine	32	0	Columbia below dams	2.45%	1.15%	
COL-3	Big Creek	23	0	Columbia below dams	1.54%	1.45%	
COL-4	Grays River	34	0	Columbia below dams	1.40%	1.13%	
COL-5	Elochoman	80	0	Columbia below dams	1.21%	0.38%	
COL-6	Abernathy	87	0	Columbia below dams		0.60%	
COL-7	Cowlitz	193	0	Columbia below dams	2.08%	0.60%	2.36%
COL-8	North Toutle	187	0	Columbia below dams	2.42%	0.50%	
COL-9	Fallert Creek	119	0	Columbia below dams	1.29%	0.84%	
COL-10	Kalama Falls	126	0	Columbia below dams	3.24%	0.62%	
COL-11	Lewis River	148	0	Columbia below dams	2.13%	1.35%	0.50%
COL-12	Clackamas	225	0	Willamette River		0.22%	1.05%
COL-13	Eagle Creek	230	0	Willamette River	1.38%		0.72%
COL-14	Stayton	373	0	Willamette River		0.44%	
COL-15	Marion Forks	406	0	Willamette River		0.24%	0.62%
COL-16	South Santiam	418	0	Willamette River		0.95%	0.93%
COL-17	McKenzie	386	0	Willamette River		0.46%	0.55%
COL-18	Dexter	406	0	Willamette River		1.17%	0.63%
COL-19	Willamette	536	0	Willamette River		0.83%	0.91%
COL-20	Sandy River	221	0	Columbia below dams	3.42%		
COL-21	Washougal	225	0	Columbia below dams	1.53%	1.14%	
COL-22	Wahkeena	200	0	Columbia below dams	1.24%		
COL-23	Bonneville	235	0	Columbia below dams	1.92%	0.44%	0.88%

Label	Hatchery	Upstream (km)	Dams	Columbia Segment	Coho Surv	Fall Surv	Spring Surv
COL-24	Cascade	243	1	Columbia above dams	1.41%		
COL-25	Oxbow	243	1	Columbia above dams	3.16%		
COL-26	Carson	262	1	Columbia above dams			0.26%
COL-27	Little White Salmon	257	1	Columbia above dams		0.25%	0.22%
COL-28	Willard	269	1	Columbia above dams	0.51%		
COL-29	Spring Creek	270	1	Columbia above dams		0.48%	
COL-30	Klickitat	322	1	Columbia above dams	1.21%	0.24%	0.39%
COL-31	Warm Springs (OR)	484	2	Columbia above dams			0.10%
COL-32	Round Butte	505	2	Columbia above dams		0.16%	0.74%
COL-33	Umatilla	451	3	Columbia above dams		0.14%	0.17%
COL-34	Yakima	671	4	Columbia above dams		0.06%	
COL-35	Ringold Springs	563	4	Columbia above dams		0.76%	
COL-36	Priest Rapids	639	4	Columbia above dams		0.88%	
COL-37	Dryden Pond	789	7	Columbia above dams			0.15%
COL-38	Leavenworth	819	7	Columbia above dams		0.02%	0.11%
COL-39	Chiwawa	848	7	Columbia above dams			0.09%
COL-40	Turtle Rock	763	8	Columbia above dams			0.96%
COL-41	Entiat	798	8	Columbia above dams		0.01%	0.05%
COL-42	Wells Dam	829	8	Columbia above dams		0.09%	0.35%
COL-43	Winthrop	930	9	Columbia above dams			0.04%
COL-44	Methow	932	9	Columbia above dams			0.06%
COL-45	Similkameen	991	9	Columbia above dams			0.65%
COL-46	Lyons Ferry	625	6	Snake River		0.25%	0.64%
COL-47	Hagerman	827	8	Snake River		0.57%	
COL-48	Dworshak	827	8	Snake River		0.04%	0.04%
COL-49	Kooskia	877	8	Snake River			0.04%
COL-50	Lookingglass	803	8	Snake River		0.04%	0.11%
COL-51	Rapid River	867	8	Snake River			0.06%
COL-52	McCall	966	8	Snake River			0.08%
COL-53	Sawtooth	1444	8	Snake River		0.00%	0.03%

Notes:
Numbers in the Label field correspond to the hatchery labels in Figures 3 through 7.
The Upstream field shows the distance from the hatchery to the river mouth, following the watercourse, and Dams is the number of dams between the hatchery and the river mouth.
See Figure 7 for dam locations and names.
In the table headings, “Surv” is used as shorthand for average survival rate.