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A PRELIMINARY ANALYSIS OF CHINOOK SALMON CODED-WIRE TAG RECOVERY DATA FROM IRON GATE, TRINITY RIVER AND COLE RIVERS HATCHERIES, BROOD YEARS 1978-2001

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Chapter 1

Introduction

This report constitutes the second of two deliverable products developed though the “Iron Gate Hatchery” contract awarded by the Hoopa Valley Tribal Council to Dr. David Hankin via the Humboldt State University Sponsored Projects Foundation. The first deliverable product, consisting of an overview of the annual salmon and steelhead propagation process at Iron Gate Hatchery, including recommendations for modest changes that would assist introduction of a constant fractional marking program, was delivered in January 2008 and was finalized in March 2008 (Logan and Hankin 2008).

This second deliverable product consists of a preliminary analysis of coded-wire tag (CWT) recovery data compiled from nearly 25 years of releases from each of three hatcheries and four races of Chinook salmon: fall Chinook salmon released from Iron Gate Hatchery (upper Klamath River, California), spring and fall Chinook salmon released from Trinity River Hatchery (upper Trinity River, California), and spring Chinook salmon released from Cole Rivers Hatchery (upper Rogue River, Oregon). The primary objective of these analyses was to determine the degree to which estimated brood year survival rates for comparable releases were correlated with one another across hatcheries and races so as to evaluate (a) the potential use of hatchery fish survival rates as a proxy for ocean survival conditions shortly following releases, and (b) to determine if the ratios of survival rates for fish released from Iron Gate Hatchery as compared to Trinity River Hatchery have recently become less than in earlier years, possibly due to changes in water management in the upper Klamath River. A recent stock-recruitment analysis of Klamath River fall Chinook salmon (STT 2005) used mean brood year survival rates of fingerling releases of fall Chinook salmon from Iron Gate and Trinity River hatcheries as a proxy for *post-rearing survival* conditions and thereby considerably improved the fit of a Ricker stock-recruitment model for Klamath fall Chinook salmon. Presumably, variation in post-rearing survival is primarily a reflection of variation in ocean survival conditions. If so, then one might expect to see strong covariation of survival rates, for similar release types and races, for CWT groups released from Iron Gate, Trinity River, and perhaps also Cole Rivers hatcheries.

In addition to the principal focus on survival rates, analyses of CWT recovery data were also designed to shed light on the degree to which age-specific maturation probabilities and size at age were affected by stock type and by release strategy. In an earlier analysis of just three or four brood years of CWT recovery data for Chinook salmon released from California and Oregon hatcheries, Hankin (1990) believed he had identified consistent effects of release type on maturation schedules, fishery exploitation and size at age. It was of interest to determine whether or not these apparent patterns would be reinforced or modified based on analysis of this much longer, approximately 25 year, period of brood releases.

The analyses described in this report were carried out with future improvement of marking at Iron Gate Hatchery as a principal interest, with a specific objective of introducing a constant fractional marking (CFM) program, ideally at a 25% marking rate that would match that used at Trinity River Hatchery since the 2000 brood year. At Iron Gate Hatchery, as at many other Chinook salmon hatcheries, juvenile Chinook are released as subyearlings during early summer (e.g., June releases of *fingerlings*) or during early fall (e.g., October releases of *yearlings*). Fingerlings typically average about 90 fish per pound (about 5 g) at release whereas yearlings typically average 9-10 fish per pound (about 45-50 g) at release. At Iron Gate Hatchery (IGH), annual releases consist of about 5 million fingerling and 900 thousand yearling fall Chinook salmon. At Trinity River Hatchery (TRH), annual releases of fall Chinook salmon are about 2 million fingerlings and 900,000 yearlings, and annual releases of spring Chinook salmon are about 1 million fingerlings and 400,000 yearlings. Cole Rivers Hatchery (CRH) annually releases about 1.6 million spring Chinook salmon “smolts”, subyearlings released from August through October; these fish are similar in size to the yearlings released from IGH and TRH.

The large number of fingerlings released from IGH creates substantial logistical issues with respect to implementation of a constant fraction marking (CFM) program. Therefore, we developed alternative mixes of fingerling and yearling releases that, based on our CWT analyses, would generate similar total catches and escapement. If fewer fingerlings but more yearlings were released, then implementation of a 25% CFM program would be more feasible.

Finally, over the past 25 years there have been substantial changes in ocean and freshwater fisheries regulations. In particular, restrictions to ocean fishing due to legal recognition of legitimate Indian fishing rights by Hoopa and Yurok tribes in the Klamath River (Parravano v. Babbitt 1995) have reduced the number of CWT recoveries in ocean fisheries and have thereby reduced the accuracy with which ocean fishery exploitation rates can be estimated from a CWT release group of fixed size. Therefore, we engaged in some simplified but, we think, useful simulations of variances of estimated life history and fishery parameters based on standard cohort analysis methods as a function of CWT release group size. These simulation results can provide substantial guidance concerning appropriate release group sizes given reduced ocean fisheries.

Chapter 2

Data Sources and Manipulations

We compiled CWT release and recovery data for four hatchery stocks of Chinook salmon: Iron Gate Hatchery (IGH) and Trinity River Hatchery TRH (TRH) Fall Chinook salmon; TRH spring Chinook salmon; and Cole Rivers Hatchery (CRH) spring Chinook salmon. For each stock, the basic categories of data types included (a) release information; (b) estimated ocean recoveries; (c) estimated freshwater returns; and (d) lengths at hatchery return.

2.1 Releases

Information about hatchery releases of CWT Chinook was obtained from the Pacific States Marine Fisheries Commission's (PSMFC) coded-wire tag database, known as the *regional mark processing center*, or RMPC. Information was obtained for IGH and TRH fall Chinook releases from brood years 1978 through 2004, TRH spring Chinook releases from brood years 1976 through 2004, and CRH spring Chinook releases from brood years 1975 through 2005.

Releases from each hatchery and brood year often included several coded-wire tag (CWT) release groups. In general, the RMPC release table includes one data record per CWT release group. Release information for each CWT release group includes tag code, species, race, brood year, release date, average size, release group size (number released with adipose fin clip and coded-wire tag), agency, hatchery, and release location.

In most cases RMPC information was found to be accurate and complete. However, we did find and correct some important errors in RMPC release data. In particular, three 2001 brood year spring Chinook CWT release groups (093515, 093517, and 093518) from CRH were erroneously labeled as fall Chinook release groups. Also, we found that RMPC release records for tag codes 060830 and 060831 released from

IGH were erroneous duplicates of the release records for tag codes 063830 and 063831.

It was often challenging to determine, from RMPC release location data, whether individual CWT groups were released directly from or near the hatchery rearing location (*on-site* releases). Fish released at locations distant from the hatchery of rearing (*off-site* releases) tend to stray (fail to return to hatchery of origin) at much higher rates than fish released on-site. Because stray escapement of hatchery fish to natural spawning areas may not be adequately estimated, estimates of total freshwater escapement for off-site releases may be negatively biased as compared to those for hatchery CWT groups released on-site thereby also affecting estimated survival rates and other parameters. In most, but not all, cases, off-site releases were identifiable by the entries in the *release location code* field of the CWT release table. We restricted our CWT analyses to those groups which we believed to have been released on-site. In the Klamath-Trinity and Rogue systems relatively few CWT groups have been released off-site and these have often been small (e.g., IGH pond program in 1980s), and essentially none are currently released off-site.

2.2 Ocean Recoveries

RMPC was the original source of all records of ocean recoveries of CWT Chinook. However, because CWT recovery data have been subjected to intensive scrutiny for management of Klamath River Chinook, we took advantage of summarized records of ocean recoveries of IGH and TRH CWT fall Chinook that had been prepared for KOHM (Klamath Ocean Harvest Model) purposes (A.Grover, CDFG, pers. comm.). The KOHM records were re-processed in our project so as to produce the statistical summaries required for our calculations. KOHM summaries were generally by hatchery, release type and month, whereas summaries required for our project analyses were generally by individual CWT code and year.

For most analyses in our project, it was adequate that KOHM ocean CWT recovery records were summarized by month of capture, but other analyses required date of ocean captures. To produce such data, we modified and ran one of the KOHM initial programs to generate a table that included capture date for individual observed recoveries. The output records were otherwise identical to those produced in the original KOHM table.

Individual ocean CWT recoveries were labeled as occurring before or after the assumed *cut-off date* for river entry for fish maturing in that year. For TRH and CRH spring Chinook, we assumed that age i maturing fish would entry freshwater prior to June 15, and for IGH and TRH fall Chinook we (initially) assumed that all age i maturing fish entered freshwater prior to September 1 (consistent with KOHM assumptions). For these *cut-off dates* we determined the estimated number of ocean recoveries at age i prior to and following the cut-off dates. Because application of our cohort analysis methods (see below) to CWT recovery data using the September 1 cut-off date produced some implausible results, particularly for TRH fall Chinook, we explored the consequences of using alternative cut-off dates of 15 September and 01 October, respectively. For each CWT code and fish age (year), ocean recoveries were summed for the periods prior to and following the cut-off dates, and were summed by fishery type (sport or commercial) within those intervals. Similarly, estimated non-landed mortalities were summed for the two time intervals for the two fishery types.

2.3 Non-Landed Ocean Mortalities

2.3.1 KOHM Methods, with Minor Modifications

For the brood years of CWT releases explored in this project, ocean fisheries have been regulated such that hooked fish below legal minimum length limits (which may differ by sport and commercial fisheries) must be released. Some unknown fraction of these hooked and released fish will die. No records are kept of the numbers of fish that are hooked and released, so non-landed mortalities are therefore generally *imputed* rather than estimated from CWT recovery data. Members of the KOHM Modeling Team have devised a method for imputing ocean non-landed mortalities of IGH and TRH fall Chinook that relies on observations of landed CWT'd fish; incorporates age, release type, month of capture, expected mean and variance in length for a given month and legal minimum retention length (which may vary by year and/or fishery type); and assumes fishery-specific hooking mortality and drop-off rates. Details about the derivation and use of the KOHM method for estimating ocean non-landed mortalities are in Goldwasser at al. (2001).

In our project we modified the KOHM methods to estimate ocean non-landed mortalities for IGH and TRH fall Chinook, and applied these modified methods also to TRH spring Chinook. The modifications mainly involved minor changes in the temporal strata within which coded-wire tag recoveries and non-landed mortalities were summed. In our cohort analyses of CWT recovery data, we required non-landed mortalities by age and fishery type for two time periods (pre- and post- cut-off date) for each year for each CWT release group.

An important table in the KOHM method of estimating ocean non-landed mortalities is called *Plegal* . Table *Plegal* is used, essentially, to calculate an answer to this question: "In a cohort of Klamath River Chinook salmon originating from a release of fingerlings or yearlings, respectively, what is the expected fraction of the fish that have lengths above some given legal minimum length l_{min} at age i in month j?" Values in the *Plegal* table were derived by KOHM personnel through analysis of many sets of lengths of ocean-caught IGH and TRH Fall Chinook for specific combinations of release group, age, and month of capture. We recognize that there may be unknown errors in using the existing *Plegal* table, based on IGH and TRH fall Chinook, for imputing non-landed mortalities for TRH spring Chinook. However, a *Plegal* table for TRH spring Chinook has not yet been derived, and we believed that it would be better to apply the existing *Plegal* table rather than to ignore non-landed mortalities for releases of TRH spring Chinook salmon. Let p_{legal} be the expected fraction of fish belong to a CWT release group that are above the legal minimum size limit at age i in month j, and let $\hat{H}_{legal}$ be the estimated number of (legal-sized) fish that have been harvested in a fishery for some month. Then, assuming that legal and sublegal fish of age i are contacted at the same rate in ocean fisheries, the total number of fish from that CWT group that were *contacted* in that fishery/month stratum could be estimated as:

$$\hat{C}_{total} = \frac{\hat{H}_{legal}}{p_{legal}}$$

The imputed number of contacts with sublegal fish would therefore be:

$$\hat{C}_{sublegal} = \hat{C}_{total} - \hat{H}_{legal} = \frac{\hat{H}_{legal}(1 - p_{legal})}{p_{legal}}$$

and the imputed number of non-landed mortalities would be:

$$\hat{D}_{sublegal} = \hat{C}_{sublegal} \cdot p_{hook},$$

where p_{hook} is hooking mortality rate, set at 0.14 for recreational fisheries and 0.26 for commercial fisheries.

Non-landed ocean mortalities of CRH spring Chinook were not calculated. A spreadsheet with cohort reconstruction of CRH spring Chinook CWT release groups, provided by Tom Satterthwaite, ODFW, did include estimates of ocean non-landed mortalities. However, those estimates were calculated by methods very different from and not comparable to those used by KOHM personnel to calculate ocean non-landed mortalities for IGH and TRH fall Chinook. Therefore, when comparing estimate life history or fishery parameters across IGH, TRH and CRH stocks of Chinook salmon, we omitted inclusion of imputed non-landed ocean mortalities.

2.3.2 Alternative Methods

We believe that existing KOHM methods for imputing non-landed mortalities could be improved in two respects. First, the method described above results in zero imputed non-landed mortalities whenever there are no estimated landed recoveries of legal-sized fish. At age 2, this means that imputed non-landed mortalities are almost always zero, a result that seems highly implausible, especially for release groups at large in the early 80s when ocean fishery exploitation rates often exceeded 50%. Second, the use of a fixed set of p_{legal} values for a particular month and release type invokes an implicit assumption that interannual variation in size at age has no effect on p_{legal} values. Our analyses of mean lengths at hatchery return suggest, however, that there is dramatic interannual variation in mean length at age 3. This means that in some years an unusually large fraction of age 3 fish might exceed l_{min} and would have high p_{legal} (with correspondingly lower non-landed mortalities), whereas in other years an unusually small fraction of age 3 fish might exceed l_{min} and would have small p_{legal} (with correspondingly higher non-landed mortalities). In the Results section of this report, we briefly consider an alternative approach to imputation of age 2 non-landed mortalities, and we describe procedures and results of using mean lengths at hatchery return to generate year- and month-specific values of p_{legal} that we believe should produce more plausible imputations of non-landed mortalities at age 3.

2.4 Freshwater Recoveries

Complete records of freshwater CWT recoveries for the Klamath-Trinity basin were not available from RMPC. Summarized data for freshwater recoveries of IGH and TRH CWT fall Chinook CWT groups were instead provided by KOHM personnel. We assembled and summarized our own records of freshwater CWT recoveries of TRH spring Chinook from brood years 1976 through 2003 from data provided by CDFG and the Yurok and Hoopa Tribal Fisheries departments. Total CWT recoveries in the upper Trinity sport fishery and natural spawning areas were estimated by CDFG personnel based on Willow Creek weir mark-recapture data, hatchery returns, sport angler surveys and reward tag returns, and actual CWT recoveries. CWT recoveries in the Klamath sport fishery and natural spawning areas were also based partly on observed CWT recoveries and partly on estimation from carcass and spawner surveys, angler surveys, reward tag returns, and other sources of information.

Records of CWT spring Chinook released from CRH and recovered at CRH were available from the RMPC. However, RMPC records of recoveries of CRH CWT spring Chinook in the Rogue River sport catch and natural area spawning were incomplete or lacking. Our primary source for CRH freshwater recovery data was a spreadsheet provided by Tom Satterthwaite (ODFW) for cohort reconstruction of CRH CWT release groups. The spreadsheet was translated into a database table, and the freshwater recovery data were extracted for use in the current analysis. Some values reported in the CRH cohort spreadsheet (straying, prespawning mortality and river harvest) were often not based on actual CWT recoveries, but were derived by Satterthwaite. Pre-spawning mortalities, often substantial in the Rogue, were derived by regression analyses for years in which there were not field programs designed to estimate these mortalities.

2.5 Lengths at Hatchery Return

For each tag code and age of hatchery return, we attempted to calculate the mean and standard deviation of lengths at hatchery return; this information is not available in RMPC records. In some cases we calculated means and variances of hatchery lengths from raw length data (hatchery records). In other cases, we relied upon previously calculated length statistics available in published or unpublished reports. Below we summarize the steps that we took to generate a fairly complete series of length statistics for individual CWT groups at hatchery return.

2.5.1 TRH

Wade Sinnen, CDFG, provided a single table containing 58,622 individual records of Chinook returning to TRH in years 1990 through 2006. From that table we summarized 55,232 records of TRH spring and fall Chinook with length measurements and deciphered CWT codes (19,972 spring Chinook, 35,260 fall Chinook). Wade Sinnen also provided three tables with individual records of Chinook returns to TRH in 1987, 1988, and 1989. The original tables had 13,153 records. We summarized 10,549 lengths from measured TRH CWT spring and fall Chinook (3,634 spring Chinook, 6,915 fall Chinook). Mark Zuspan, CDFG, provided a table of spring and fall Chinook returns to TRH in years 1983 through 1985 and 1987 through 1993. The original table had 29,529 records. We summarized 7,025 CWT Chinook length records from return years 1983 through 1985 (5,471 fall Chinook, 1,554 spring Chinook) from Zuzpan's table. We also worked up CDFG TRH hatchery records (including date, tag code, and length) for CWT spring and fall Chinook returning to TRH in 1986: 2,340 records (1,327 fall Chinook, 1,013 spring Chinook). Finally, length statistics from hatchery returns of CWT groups of TRH spring and fall Chinook released from brood years from 1977 through 1980 were based on summaries presented in Hankin (1990, his Table 5, mean lengths only).

2.5.2 IGH

Mark Hampton, CDFG, provided a spreadsheet of IGH CWT fall Chinook hatchery return data from years 1986 through 2006. We translated the data to database format and summarized 14,635 lengths. Length statistics for returns of CWT fall Chinook to IGH in 1984 were calculated from hardcopy IGH hatchery records, based on

444 records. Length statistics for IGH CWT fall Chinook released from brood years 1976 through 1980 were based on Hankin (1990, his Table 6, mean lengths only).

2.5.3 CRH

RMPC records provided lengths of individual CWT recoveries at CRH for brood years 1979 through 2000 (return years 1981 2005). These data were summarized (count, mean, standard deviation) for each tag code and age. Additional mean lengths for 1975 through 1980 brood year recoveries of CRH CWT spring Chinook recovered at CRH at ages 2 through 4 were based on Hankin (1990, his Table 3, mean lengths only). Length data for CWT recoveries at CRH in 2006 were provided by John D. Leppink, Oregon CWT Data Base Coordinator.

2.6 Mean Weights at Release

Theoretically, mean weights at release should be recorded in RMPC records for every individual CWT release group. Prior to the 1997 brood year at TRH, typically just a single CWT code was used to "represent" all fingerling releases of fall or spring Chinook salmon and mean weight at release was recorded for such CWT groups. Beginning with the 1997 brood year, however, constant fractional marking (Hankin 1982) of releases from all raceways was initiated and distinctive codes were applied to fish from individual raceways to allow assessment of the possible influence of size at release on subsequent survival rates. As noted previously (see Zajanc and Hankin 1998), fish are ponded sequentially in raceways at TRH, according to spawning dates of parents, so that the fish that are ponded first (from earliest-spawning parents) typically have larger mean weight at release than fish that are ponded last from latest-spawning parents.

Mean weights of individual CWT release groups have not, however, been consistently measured or reported at TRH and it appears that this has also been the case at IGH. Instead, at TRH (and apparently also at IGH) in many years only a single mean weight has been reported for from 2-9 distinct CWT codes. Reasoning that fish ponded from later-spawning parents would, at the time of release, have a smaller mean size than fish ponded from earlier-spawning parents, we developed methods to make a reasonable guess of mean release size for individual CWT groups when reported mean weights at release corresponded to fish reared in more than one raceway. We emphasize that these are at best reasonable guesses. Unfortunately, in all but one instance, we had no way to determine whether or not these guessed weights are close to true mean weights at release.

Mean weight at release data were not available for individual TRH CWT releases in 1999, 2000 or 2001 BYs. Instead, mean weights were reported for CWT groups reared in 2-3 adjacent raceways. Based on information on raceway rearing locations, we generated plausible mean weights at release for individual CWT groups. For the 1999 BY, there were two pairs of CWTs from adjacent pooled raceways. We assumed that the reported mean weight for two pooled adjacent raceways was equal to a weighted average of the mean weights in the adjacent raceways. Let N_j be the number released from raceway j ($j = 1, 2$), let w_j be the mean weight of fish from raceway j, and let $\bar{w}$ be the mean weight for the combined raceways. Then $\bar{w} = (N_1 w_1 + N_2 w_2)/(N_1 + N_2)$. We next assumed that the mean weights of fish from adjacent raceways for all four CWT groups released from the 1999 brood year differed from one another by a constant amount x. Let y denote the mean weight of the CWT release group (CWT #065257) that was ponded last for the 1999 BY. Then, the mean weights of fish in previously ponded raceways were assumed to be $y + x$ (065256), $y + 2x$ (065255), and $y + 3x$ (065254). This setup leads to creation of the following simultaneous equations:

$$\begin{aligned}
\frac{N_1 y + N_2(y + x)}{N_1 + N - 2} &= \bar{w}_{1,2} = 5.02 \\
\frac{N_3(y + 2x) + N_4(y + 3x)}{N_3 + N_4} &= \bar{w}_{3,4} = 5.71,
\end{aligned}$$

where 5.02 and 5.71 are the mean weights (g) reported for the combined CWT groups (065257 and 065256) and (065255 and 065254), respectively. These simultaneous equations were solved for x (giving a result of 0.3362 g) and y (giving a result of 4.8562 g), thereby generating plausible mean weights at release of 4.86 g, 5.19 g, 5.53 g, and 5.86 g, respectively, for CWT groups 065257, 065256, 065255, and 065254, respectively. These calculated weights are similar to corresponding mean weights that we calculated based on earlier hatchery weight records for fish (prior to release) from individual raceways: 4.89 g, 5.14 g, 5.38 g, and 6.10 g, respectively.

For the 2000 BY, there were an unusually large number of individual CWT groups. Three separate CWT codes were used to tag fish from raceway C3/4 (with a reported pooled weight of 5.27g); a single CWT was used to tag fish from raceway C1/2 (reported mean weight = 6.87 g); and 3 CWT codes each were used to tag fish from raceways A1/2, A3/4, and B1/2, respectively, with a single pooled mean weight reported for all of these CWT groups (8.10 g). As for the 1999 BY releases, we assumed that the reported mean weight across all three raceways should theoretically equal a weighted mean weight from the individual races, so that:

$$8.10g = \frac{N_1 y + N_2(y + x) + N_3(y + 2x)}{N_1 + N_2 + N_3}$$

where N_1, N_2, and N_3 are the numbers of fish in raceways B1/2, A3/4 and A1/2, respectively. We constructed a program in R that generated guesses for x, given y, so as to achieve the reported mean weight of 8.10 g and also ensure that the mean weight of fish from raceway B1/2 exceeded the reported mean weight of fish released from raceway C1/2 (6.87 g).

For the 2001 BY, two pairs of CWT release groups were released from two sets of adjacent raceways with a single reported mean weight for each of these adjacent raceway pairs. We were able to generate plausible guesses for raceway-specific weights for these 2001 BY release groups using the previously-described simultaneous equation approach used for 1999 BY CWT releases.

Chapter 3

Analysis and Simulation Methods

3.1 Basic Cohort Analysis/Estimation Methods

We adopted a cohort analysis approach that is similar to, though not identical with, the analysis methods that are currently used by the KOHM modeling team in the context of regulation of ocean salmon fisheries. Our analysis methods differ in two chief respects.

First, we make no attempt to account for ocean natural mortalities that may occur during ocean fishing seasons. Instead, we assume that no natural mortalities occur during ocean fishing seasons but that all ocean natural mortalities occur between the end of one year's fishing season and the beginning of the next year's fishing season. Second, we define age classes to begin with the numbers alive immediately prior to the beginning of spring ocean fisheries whereas current analysis methods appear to instead employ a "birth-date" (termed cut-off date in this report) of September 1, after which a cohort increases in age by one year. Neither of these differences should have any substantial impact on relative values of most estimated parameters, but choice of "birth-date" can have a substantial impact on estimation of ocean exploitation rates following maturation at age (see **Ocean Fishery Cut-Off (Birth-) Date** below).

We assume that Chinook salmon from the Klamath and Rogue rivers may mature at ages two through five only. Define the following cohort model variables:

$A_i(t)$ = spring ocean abundance at age i, immediately prior to fishing in year t;

$C_{i,pre}(t)$ = ocean fishery landings (recreational and commercial) at age i in year t, prior to the *cut-off* date after which immature fish only are assumed to remain in the ocean;

$C_{i,post}(t)$ = ocean fishery landings (recreational and commercial) at age i in year t, following the *cut-off* date;

$H_i(t)$ = freshwater harvest (net + sport) at age i in year t;

$S_i(t)$ = total freshwater escapement (freshwater harvests plus hatchery returns plus stray escapement) at age i in year t.

The numbers of fish that remain alive at age and that are available for capture or escapement at age depend on two additional sets of model parameters and a final single parameter:

$p_i(t)$ = probability of surviving natural causes of death between ages i and $i+1$ over the interval from the end of ocean fisheries in year t to the beginning of ocean fisheries in year $t+1$;

$\sigma_i(t)$ = (conditional) age-specific maturation probability = probability of maturing at age i given alive at age i and not captured in ocean fisheries in year t prior to the cut-off date;

$p_0(t)$ = probability of surviving from release to ocean age 2, just prior to ocean fisheries, for a cohort released from brood year t.

For cohort analysis based on recoveries from a single CWT release group, one must assume either that the ocean survival rates, the $p_i(t)$, are known or that the $\sigma_i(t)$ are assumed known and are time-invariant. We assume that the $p_i(t) = p_i$ are known, as is common practice, and we fix $p_2 = 0.50$ and $p_3 = p_4 = 0.80$.

Having defined the above variables and parameters, our cohort analysis proceeds from the oldest age as outlined below (omitting year-specific notation, which is assumed implicit), substituting estimated values for the $C_{i,pre}$, $C_{i,post}$, and S_i:

At Age 5, assuming that all fish mature by age 5:

$$\hat{A}_5 = \hat{C}_{5,pre} + \hat{S}_5$$

At Ages 3 and 4:

$$\hat{A}_i = \frac{\hat{A}_{i+1}}{0.80} + \hat{C}_{i,pre} + \hat{C}_{i,post} + \hat{S}_i$$

At Age 2:

$$\hat{A}_2 = \frac{\hat{A}_3}{0.50} + \hat{C}_{2,pre} + \hat{C}_{2,post} + \hat{S}_2$$

Let the numbers of fish belonging to a CWT release group be denoted by R. Then, survival from release to age 2, just prior to ocean fisheries, can be estimated as:

$$\hat{p}_o = \frac{\hat{A}_2}{R}$$

Conditional age-specific maturation probabilities at ages $i = 2, 3, 4$ can be estimated as:

$$\hat{\sigma}_i = \frac{\hat{S}_i}{\hat{A}_i - C_{i,pre}}$$

Pre-maturation and post-maturation ocean fishery exploitation rates, $E_{i,pre}$ and $E_{i,post}$, can be estimated as:

$$\begin{aligned}\hat{E}_{i,pre} =& \frac{\hat{C}_{i,pre}}{\hat{A}_i} \\ \hat{E}_{i,pos} =& \frac{\hat{C}_{i,pos}}{\hat{A}_i - \hat{C}_{i,pre} - \hat{S}_i}\end{aligned}$$

Finally, age-specific freshwater exploitation rates, u_i, can be estimated as:

$$\hat{u}_i = \frac{\hat{H}_i}{\hat{S}_i}$$

3.1.1 Ocean Fishery Cut-Off (Birth-) Date

In cohort analyses of CWT recoveries for Klamath River fall Chinook salmon, a cut-off date of 01 September has been used to separate ocean fishery catches consisting of immature and maturing Chinook (prior to the cut-off date) from those consisting of immature fish only (following the cut-off date). At a January 2008 meeting considering some of the preliminary findings from our research, D. Hillemeier (Yurok Tribal Fisheries) noted that use of this September 1 cut-off date might be responsible for what appeared to be unrealistically high estimates of post-season ocean fishery exploitation rates for Trinity River fall Chinook salmon, and he also noted that TRH Chinook enter the lower Klamath River net fishery later than IGH fall Chinook. We therefore explored the consequences of adopting alternative cut-off dates of 15 September and 01 October. Using those alternative cut-off dates, we evaluated their merits by examination of the plausibility of estimated post-season ocean fishery exploitation rates for TRH Chinook, in particular, and the relative agreement between exploitation rates estimated for IGH and TRH fall Chinook. Alteration of the cut-off date required that we generate corresponding estimates of ocean fishery catches on non-landed mortalities prior to and following the alternative cut-off dates, but there were otherwise no changes made in cohort analysis estimation methods.

3.1.2 Pooling Across Release Groups Within Brood Years

To simplify presentation and interpretation of cohort analysis results, we calculated weighted averages of estimated parameters across multiple CWT releases groups of the same type released from the same brood year. Let $\hat{\theta}_{ij}$ be an estimated parameter based on recoveries of CWT group i ($i = 1, 2, \ldots, k$) released in year j, and let R_i denote corresponding release group sizes. Then, pooled parameter estimates for year j were calculated as:

$$\hat{\hat{\theta}}_j = \frac{\sum\limits_{i=1}^{k} \hat{\theta}_{ij} R_i}{\sum\limits_{i=1}^{k} R_i}$$

3.2 Simulation of Estimator Variances vs CWT Release Group Size

We explored the relationships between variances of estimated life history and fishery parameters and CWT release group size by constructing a simplified simulation model. Given release of a known number of fish belonging to a CWT release group, we assume that a multinomial model adequately captures the essential structure of the true (but unknown) numbers of fish that are accounted for by a simplified set of fates: caught in the pre-maturation or post-maturation ocean fisheries at age i; maturing and returning to freshwater at age i. The probabilities of each of these events can be expressed in terms of the cohort analysis model parameters previously described. For example, P(captured in pre-maturation fishery at age 3)=

$$S_0(1 - E_{2,pre})(1 - \sigma_2)(1 - E_{2,post})p_2 E_{3,pre}$$

The multinomial model should provide a good theoretical representation of the variability in the actual outcomes (fates) suffered by individual fish, assuming that fates of individual fish are independent of one another.

Superimposed on this natural "process" variability is uncertainty in the numbers of fish that suffer specific fates as it depends on sampling error. For example, not all fish in the ocean catch are examined for presence of adipose-fin clips which indicate presence of a CWT. Instead, only about 20% of the ocean catch is sampled at random. We very crudely modeled variability due to sampling by assuming a 20% sampling rate for all outcomes (fates). Further, we assumed that, given the 20% sampling rate, the numbers of observed CWTs would be Poisson distributed with mean and variance equal to 20% of the expected outcome under the multinomial model. The simulated numbers of CWT'd fish observed via sampling were then scaled up by a factor of 5 to account for the 20% sampling fraction.

Give the above simulation structure, fishery and life history parameters were set equal to the mean estimated values for IGH fingerling releases of fall Chinook salmon that were at large over the period 1996 through 2006 to represent "current conditions". We assumed that annual survival rates were known and equal to those assumed for cohort analysis methods. For each simulated complete outcome of the mutually exclusive fates of a CWT release group and associated Poisson sampling, we applied our cohort analysis methods to calculate estimates of life history and fishery parameters, and we calculated expected values, bias, variance, and mean square error over a large number $(100,000)$ of such independent simulations. We varied the number of fish in release groups to determine the relationships between release group size and variability in estimates of life history and fishery parameters. We emphasize that the simulated bias and variability of estimates that we generated are conditioned on the strong (and no doubt incorrect) assumption that conditional ocean survival rates (p_2, p_3, p_4, p_5) are known.

3.3 Effects of River Flows

At the suggestion of Mark Hampton, CDFG, we explored the possibility that survival rates of IGH fingerling releases of fall Chinook might be affected by flows in the upper Klamath River at or near the time of release. We also examined the possibility that survival rates of TRH releases of Chinook salmon might be affected by flows in the upper Trinity River.

Our river flow data were monthly mean flows during June of the year of release based on USGS gauges at Seiad (upper Klamath River) and Burnt Ranch (upper Trinity River). We used simple scatterplots of estimated pooled brood year survival rates for fingerlings against mean June flows during the year of release to explore the possibility that survival rates from release to age 2 were affected by freshwater flows at time of release. We used a Monte Carlo permutation test to evaluate the possibility that the very suggestive scatterplot that emerged for IGH might have originated due to chance under a null hypothesis of independence of flows and survival rates. Methods used for this permutation test are described in the Results section, in the context of the scatterplot, without which it would be difficult to describe the logic of this statistical approach.

3.4 Alternative Mixes of Fingerling and Yearling Releases

One of the serious logistical constraints to implementation of a constant fractional marking program at Iron Gate Hatchery and, in certain years, at Trinity River Hatchery, is the very large number of fish that are released as fingerlings. Fingerlings originating from late-spawning fall Chinook parents are smaller than those originating from early-spawning parents, and there is often only a brief temporal window within which they are sufficiently large for tagging prior to release. Thus, if there are large numbers of such very small fingerlings planned for release in early June, it may be difficult or impossible to achieve a desired tagging objective for these fish. In contrast, fish released as yearlings are large and may be tagged over a much longer period of time. Therefore, if it were possible for hatcheries to reduce production of fingerlings but increase production of yearlings, and to produce similar numbers of adult returns, then the logistics of achieving a constant fractional marking program would be simplified. In addition, reduced releases of fingerlings might have reduced impacts (e.g., reduced competition, stress) on wild juveniles that appear to move downstream at a time that is similar to time of releases for fingerlings.

Based on our cohort analysis results, we averaged the estimated life history parameters for fingerling and for yearling fall Chinook salmon released from Iron Gate and Trinity River hatcheries over the brood years 1978-2001, and we averaged fishery parameters over the brood years 1990-2001, to produce performance parameters that characterized long-term average life history traits and “current” fishery management regimes which have recognized the Native American fishing rights in the Klamath River. Given these parameter sets, we calculated the expected ocean impacts (catches + non-landed mortalities), freshwater catches (net plus sport), and freshwater escapements that would result from specified releases of fingerlings and yearlings. We began with the existing production goals at the two hatcheries (2.00 million fingerlings and 0.90 million yearlings at TRH; 4.92 million fingerlings and 0.90 million yearlings at IGH), and calculated expected catches and escapements for alternative production goals that reduced the numbers of fingerlings, increased the numbers of yearlings, but achieved very similar catches and escapements. For these calculations, for a reduction in releases of y fingerlings, the releases of yearlings were increased by $y/S_{y/f}$, where $S_{y/f}$ is the ratio of average survival rates to age 2 for fish released as yearlings as compared to fingerlings. At IGH and TRH these calculated ratios were 4.088 and 5.526, respectively. This very simple rule produced essentially stable total production with relatively small changes in expected allocation of catches across ocean and freshwater fisheries.

Chapter 4

Results

4.1 Non-Landed Mortalities

Calculated values of non-landed mortalities are important in the context of ocean fishery management of Chinook salmon because fish may be caught and released at age 2, when they are almost always below legal size limits, or at age 3 when varying proportions of a cohort may be below legal size. Mortalities due to such capture and release are counted toward ocean fishery allocations of fish. Hatchery release practices (e.g., release of juveniles as fingerlings or yearlings) may influence the proportion of fish that exceed legal size at age 3, thereby also affecting non-landed mortalities in ocean fisheries. In this section we examine the importance of estimates of non-landed mortalities with respect to estimation of life history parameters; we present an alternative procedure for imputing non-landed mortalities at age 3; and we express concern regarding current methods used to calculate non-landed mortalities at age 2.

4.1.1 Importance for Parameter Estimation

Because it was impractical to develop methods for calculating non-landed mortalities for CRH spring Chinook salmon that would be analogous to those used in the KOHM process, we compared survival rates of CRH and TRH spring Chinook based on cohort analyses that ignored non-landed mortalities altogether. Ignoring non-landed mortalities would clearly lead to negative bias in estimation of ocean fishery impact rates, but may have very small impact on estimates of survival rates to age 2 and the life history parameters that were the primary focus of our research.

The two tables provided below show that exclusion of imputed non-landed mortalities from cohort analyses has a very minor but predictable impact on estimated survivorship to age two and on age-specific conditional maturation probabilities for IGH and TRH fall Chinook salmon CWT releases (pooled across multiple CWT groups released from the same brood year). Namely, estimated survival rates are slightly lower when non-landed mortalities are excluded from cohort analyses and age-specific maturation probabilities are slightly higher when non-landed mortalities are excluded. For example, for Iron Gate fall Chinook salmon released as fingerlings, a linear regression of estimated age 3 maturation probabilities estimated excluding non-landed mortalities against estimated age 3 maturation probabilities including non-landed mortalities had a near perfect correlation (adjusted R-square = 0.9997), a slope not significantly different from 1 (0.996 +/- 0078), and a small but significant positive intercept (0.0057). The effects are so minor that it is very clearly meaningful to compare life history and survival parameters across stocks (i.e., TRH spring Chinook vs CRH spring Chinook) when non-landed mortalities are excluded from CWT recovery data for both stocks.

Survival to Age 2

	KOHM Non-Landed Mortalities		Non-Landed Mortalities Excluded	
Brood Year	IGH Fingerlings	TRH Yearlings	IGH Fingerlings	TRH Yearlings
1979	0.03126	0.07167	0.02940	0.06614
1980	0.01080	0.05053	0.01038	0.04975
1981	0.01904	0.01864	0.01863	0.01832
1982	0.00627	0.04256	0.00609	0.04092
1983	0.01634	0.27139	0.01565	0.25541
1984	0.01362	0.14209	0.01305	0.13767
1985	0.01021	0.14516	0.00973	0.13992
1986	0.00062	0.11545	0.00061	0.10971
1987	0.00088	0.02185	0.00082	0.02056
1988	NA	0.01716	NA	0.01707
1989	0.00029	0.00323	0.00028	0.00319
1990	0.01345	0.00428	0.01330	0.00427
1991	0.00261	0.01093	0.00258	0.01081
1992	0.02579	0.12683	0.02548	0.12562
1993	0.00102	0.01851	0.00101	0.01846
1994	0.00166	0.01621	0.00165	0.01605
1995	0.00158	0.07281	0.00158	0.07264
1996	0.00305	0.01077	0.00303	0.01072
1997	0.03884	0.10080	0.03821	0.09975
1998	0.01133	0.05617	0.01120	0.05557
1999	0.01628	0.07803	0.01598	0.07648
2000	0.00977	0.09080	0.00946	0.08802
2001	0.00039	0.08784	0.00036	0.08286

Maturation
Probabilities

	KOHM Non-Landed Mortalities		Non-Landed Mortalities Excluded	
Brood Year	σ_3: IGH Finger.	σ_2: TRH Finger.	σ_3: IGH Finger.	σ_2: TRH Finger.
1979	0.44618	0.05144	0.45710	0.05325
1980	0.47666	0.32339	0.48382	0.32609
1981	0.36791	0.11503	0.37204	0.11623
1982	0.38596	0.02489	0.39388	0.02541
1983	0.23345	0.18394	0.23900	0.19151
1984	0.15823	0.09125	0.16207	0.09496
1985	0.47868	0.12343	0.48472	0.12787
1986	0.39049	0.21811	0.39855	0.22286
1987	0.13675	0.13196	0.13675	0.13449
1988	NA	0.19652	NA	0.19817
1989	0.56368	0.22330	0.56368	0.22330
1990	0.59997	NA	0.60245	NA
1991	0.39910	0.14692	0.40127	0.14773
1992	0.60288	0.07122	0.60621	0.07240
1993	0.47021	0.05459	0.47098	0.05504
1994	0.40570	0.06674	0.40804	0.06698
1995	0.71663	0.06806	0.71808	0.06835
1996	0.48638	0.02330	0.48701	0.02341
1997	0.85647	0.04179	0.85815	0.04217
1998	0.53461	0.04828	0.53726	0.04881
1999	0.37217	0.01069	0.37614	0.01085
2000	0.46727	0.04492	0.47588	0.04633
2001	0.70451	0.06270	0.70604	0.06526

4.1.2 Alternative Methods for Calculations of Non-Landed Mortalities

Age 3 Non-Landed Mortalities

As noted in the Methods section of this report, current KOHM methods for calculating ocean non-landed mortalities at age 3 rely on an implicit simplification (or assumption) that monthly mean length and variance in length at age (for a given stock and release type, e.g. IGH fall Chinook released as fingerlings) are fixed parameters without interannual variation . Assuming that mean length at age, measured among returning hatchery spawners, provides a good index of size at age, there is strong evidence (see below: Covariance Among Estimated Parameters Across Hatcheries and Races/Size at Age) that this implicit simplification is seriously violated. Indeed, interannual variation in size at age is quite striking. Because age 3 Chinook are generally only partially vulnerable to ocean harvest (i.e., a substantial proportion of a cohort may be below the legal size limit during a particular month), assumption of an invariant growth pattern can theoretically lead to serious underestimation or overestimation of non-landed mortalities in a given fishing season according to whether size at age for a given cohort is much smaller than or much larger than the expected long-term average. Below, we propose an alternative method for calculating non-landed mortalities that accounts for interannual variability in length at age.

For existing KOHM methods, we begin with an estimated number of fish landed (by hatchery CWT group, TRH or IGH, and release type, fingerling or yearling) in the ocean fishery at age 3. "Lookup tables" are then used to find the expected mean fish length (for that month), variance in length (for that month), minimum size limit in effect, and thereby calculate an expected proportion of the fish that would exceed legal size, P_{legal}, for that month and location. This calculated P_{legal} value is then used to generate an estimated non-catch mortality experienced by fish of sub-legal size. Although this method of calculating non-landed mortalities makes a good deal of sense, failure to account for the very substantial interannual variation in size at age may lead to substantial errors in imputed non-landed mortalities. We propose to incorporate interannual variation in length at age in the following manner.

Let μ_{3i} denote the expected mean length of an age 3 fish originated from a given release type and hatchery during month i, and let σ_i^2 denote the associated expected variance in length at age. (These values are available from the Lookup Tables.) Let $\mu_3^*(t)$ denote the observed mean age 3 length, measured at hatchery return, in year t; let $\overline{\mu_3} = \sum_{t=1978}^{2001} \mu_3^*(t)/24$ denote the observed grand mean length at age 3, measured at hatchery return, over all CWT groups of a given race and release type; and let $\sigma_{\mu_3}^2 = \sum_{t=1978}^{2001} (\mu_3^*(t) - \overline{\mu_3})^2/(24-1)$, the observed interannual variance among the hatchery mean lengths at age 3. We wish to use the observed hatchery mean lengths at age 3, $\mu_3^*(t)$, to adjust the expected mean lengths at age 3 in ocean fisheries, the μ_{3i}, thereby producing the adjusted values $\mu_{3i}^*(t)$.

If lengths at age 3 are normally distributed in the ocean and at hatchery return, we believe that it may be reasonable to invoke the following equality:

$$\frac{\mu_{3i}^*(t) - \mu_{3i}}{\sigma_{3i}} = \frac{\mu_3^*(t) - \overline{\mu_3}}{\sigma_{\mu_3}} \tag{4.1}$$

Solving equation 4.1 for $\mu_{3i}^*(t)$ gives:

$$\mu_{3i}^*(t) = \mu_{3i} + (\mu_3^*(t) - \overline{\mu_3})\frac{\sigma_{3i}}{\sigma_{\mu_3}} \tag{4.2}$$

The adjusted values $\mu_{3i}^*(t)$ would then be used to calculate age 3 non-landed mortalities in the usual manner used in KOHM analyses except that $\mu_{3i}^*(t)$ would replace μ_{3i}.

Based on lengths of individual fish measured at hatcheries, it appears that variance in length at age increases with mean length at age. Therefore, it is probably appropriate to also modify variance in length at age once mean length at age has been adjusted as suggested above. Rather than use the assumed constant σ_{3i} from the lookup tables, it would probably be better to assume a constant coefficient of variation (standard deviation/mean). In analysis of extensive hatchery length data, we found that coefficients of variation in length at age had essentially no trend with mean length (see Figure 4.1) and averaged about 0.0813. Therefore, expected standard deviation could be calculated as 0.0813 times $\mu^*_{3i}(t)$.

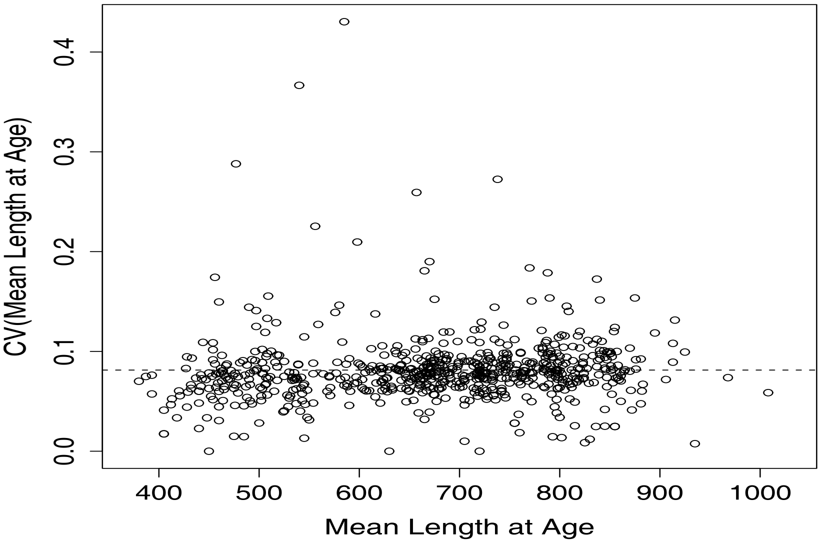


Figure 4.1. Coefficients of variation (CV = standard deviation/mean) in length at ages 2-4 among returning fall Chinook hatchery spawners at TRH and IGH, 1978-2001 brood years. Horizontal dotted line shows value of mean CV (0.0813).

Table 4.1 compares age 3 non-landed mortalities calculated using the current KOHM methods and our proposed alternative method (including CV adjustment) for two IGH yearling CWT release groups for which the mean lengths for that yearlings from corresponding brood years had unusually large (1982 BY CWT code 065908, 724 mm, 28.58 in) and small (1980 BY CWT code 065906, 590 mm, 23.23 in) mean lengths, measured at hatchery return, compared to the approximately 25 years average (648 mm, 25.52 in). For the release group with unusually large length at age 3, the total number of non-landed mortalities imputed by the proposed revised method was just 19.2% that for calculated using existing KOHM methods; for the release group with unusually small length at age 3, the total number of imputed non-landed

Table 4.1. Imputed non-landed mortalities during the months of May through October for two illustrative IGH CWT groups releases of yearlings from brood years for which the mean lengths were unusually large (065906) or unusually small (065908). Column headings with asterisks are based on our proposed methods; headings without asterisks are those based on the existing KOHM calculations. Calculation methods including the size adjustment are otherwise consistent with the existing KOHM methods. Mean lengths and standard deviations (S.D.) in inches.

CWT 065906

	Existing KOHM			Proposed Length-Adjusted		
Month	$\bar{l}_3$	S.D.	$\widehat{NLM}$	$\bar{l}_3^*$	$S.D.^*$	$\widehat{NLM}^*$
5	24.4	2.3	37.1	29.8	2.4	3.4
6	26.4	2.3	16.7	31.8	2.6	3.1
7	26.4	2.3	13.8	31.8	2.6	4.7
8	26.5	2.4	71.2	32.2	2.6	14.9
9	26.6	2.3	27.1	31.9	2.6	5.8
10	26.4	2.1	3.1	31.4	2.6	0.6
			...			...
Total:			169.0			32.9

CWT 065908

	Existing KOHM			Proposed Length-Adjusted		
Month	$\bar{l}_3$	S.D.	$\widehat{NLM}$	$\bar{l}_3^*$	$S.D.^*$	$\widehat{NLM}^*$
5	24.4	2.3	9.4	20.3	1.7	10,917.1
6	26.4	2.3	7.9	22.4	1.8	326.6
7	26.4	2.3	11.9	22.4	1.8	533.2
8	26.5	2.4	5.9	22.3	1.8	325.5
9	26.6	2.3	0.5	22.6	1.8	0.5
10	26.4	2.1	2.0	22.7	1.8	71.3
			...			...
Total:			37.6			12,174.2

mortalities was 37.6 times larger than calculated using the existing KOHM methods. Clearly, failure to account for interannual variation in length at age could have serious consequences for the errors associated with imputation of non-landed mortalities, especially when mean size at age is considerably less than the long-term average assumed in current KOHM calculations. Adjustment for CV had essentially no impact on the imputed values for non-landed mortalities.

We recognize that the results presented in Table 4.1 may be a bit extreme and that there are some unsettling aspects of the adjusted lengths. We briefly consider these issues in the Discussion section.

Age 2 Non-Landed Mortalities

The current KOHM methods for imputing non-landed mortalities generate values of zero whenever no legal-sized fish are reported captured. Imputed non-catch mortalities for age 2 Chinook will therefore almost always have zero value because it is very unusual for age 2 Klamath River Chinook to exceed the minimum size limits. Although it might be argued that age 2 non-landed mortalities are not of importance because fishery allocations are all expressed in terms of adult fish (age 3 and older), this argument fails to consider the fact that ocean interceptions and non-landed mortalities of age 2 Chinook will reduce the numbers of fish surviving to be alive at age 3 and therefore should be included in overall ocean fishery impacts.

Let ϕ_{com} and ϕ_{rec} be "age 2 shaker contact" multipliers for commercial and recreational fisheries. These multipliers are intended to reflect the likelihood that commercial fishermen, in particular, deliberately avoid contact with age 2 Chinook given their lack of commercial value and/or that age 2 Chinook have ocean migration patterns that are dissimilar from those for age 3 and older Chinook. Thus, the ϕ_{com} and ϕ_{rec} may be considerably less than 1. Then, assuming that no age 2 Chinook exceed legal size in a particular year, t, the expected non-landed mortalities at age 2, for a particular CWT group, in the pre-maturity fishery, would be:

$$\begin{aligned} NLM_{com}(t) =& A_2 \phi_{com} E_{pre,com}(t) p_{hook,com} \\ NLM_{rec}(t) =& A_2 \phi_{com} E_{pre,rec}(t) p_{hook,rec} \end{aligned}$$

where $E_{pre,com}(t)$ and $E_{pre,rec}(t)$ are the exploitation rates for fully vulnerable fish in year (t). To apply this kind of approach, one would have to rely on other CWT groups at large at age 4 in year t to estimate the exploitation rates for fully vulnerable fish. Also, it seems likely that the non-catch mortality rates, $p_{hook,com}$ and $p_{hook,rec}$ might be greater for age 2 fish than the 0.14 and 0.26 values, respectively, that are assumed at age 3.

In his spreadsheets for cohort analysis of Rogue River spring Chinook CWT groups released from CRH, Satterthwaite included age 2 non-landed mortalities that were calculated using a very similar method to the one proposed above. Although the ϕ_{com} and ϕ_{rec} are unknown, a range of plausible values might be conjectured (e.g., 0.2-0.5) and imputations of age 2 non-landed mortalities could be generated over this range of plausible multipliers. Only through such hypothetical calculations could one judge whether or not the current failure to address age 2 non-landed mortalities is a serious flaw in existing KOHM calculations.

4.2 Effect of Release Type

For a given stock and race (IGH fall Chinook, TRH spring or fall Chinook, CRH spring Chinook), release type had important effects on survival rates to age 2, size at age, and on age-specific ocean fishery exploitation rates and maturation probabilities. Observed effects were fully consistent with those earlier noted by Hankin (1990) based on CWT recovery data for a very limited set of brood years. Generally, release at a larger size in a later month had the following effects: (1) increased survival to age 2; (2) reduced size at age of return to freshwater; (3) reduced age 3 ocean fishery exploitation rates; and (4) reduced maturation probabilities at ages 2 and 3. With the exception of ocean fishery exploitation rates, we consider these effects in detail below.

4.2.1 Survival Rates versus Release Type

Mean survival rates from release to age 2 (pooled across release groups from the same brood year) were substantially greater for yearlings than fingerlings for IGH and TRH fall Chinook and TRH spring Chinook, but showed relatively little clear differences among CWT releases of CRH spring Chinook made during the months of August, September or October. Interannual variation in survival rates was extreme for IGH and TRH releases of fall and spring Chinook (maximum survival rates were from 80-250 times minimum survival rates for these stocks), but variation in survival rates was less extreme for CRH releases of spring Chinook (max/min ranged from about 12 - 23). Mean survival rates were 0.01039, 0.01285, and 0.01541 for finglering releases of IGH fall Chinook, TRH fall Chinook and TRH spring Chinook, respectively; 0.03579, 0.06608 and 0.06500 for yearling releases of IGH fall Chinook, TRH fall Chinook and TRH spring Chinook, respectively; and were 0.05490, 0.04390, and 0.04303 for CRH spring Chinook released in the months of August, September and October, respectively. Standard deviations of survival rates were nearly the same as mean survival rates for all stocks and release types at IGH and TRH and were slightly less than means at CRH (Table 4.2).

4.2.2 Survival Rates versus Size at Release

TRH

Beginning with the 1997 brood year, individual CWT groups have been released from each raceway at TRH in an attempt to ensure that there are representative CWT groups for fish released at different sizes. Theoretically, variation in size at release could lead to variation in survival and the previous practice of selecting a single "representative raceway" for coded-wire tagging would lead to erroneous extrapolations of the performance of hatchery releases when applied to the full fingerling production. Table 4.3 provides strong suggestive evidence that size at release has important

Table 4.2. Minimum, maximum, mean, number of brood years for summary statistics, and standard deviation of survival rates for fall and spring Chinook salmon released from IGH and TRH, brood years 1979-2001, and spring Chinook salmon released from CRH, brood years 1975-2001. Estimated survival rates for individual brood years were pooled over all CWT groups of the same type from a given brood year and exclude non-landed mortalities to ensure comparability of estimated values. Note that means are not always calculated over identical sets of brood years as CWT groups were not tagged from all release types in all years.

Fall Chinook

	IGH Fing.	TRH Fing.	IGH Year.	TRH Year.
minimum:	0.00028	0.00020	0.00199	0.00319
maximum:	0.03821	0.04598	0.10610	0.25540
mean:	0.01039	0.01285	0.03579	0.06608
s.d.:	0.01040	0.01464	0.02803	0.06043
n:	22	22	20	23

Spring Chinook

	TRH Fing.	CRH Aug.	CRH Sept.	CRH Oct.	TRH Year.
minimum:	0.00023	0.01196	0.00634	0.01245	0.00185
maximum:	0.05952	0.14680	0.14440	0.15120	0.24933
mean:	0.01541	0.05490	0.04390	0.04969	0.06500
s.d.:	0.01826	0.03570	0.03566	0.04303	0.06968
n:	19	19	22	25	22

effect on survival of fingerling fall Chinook salmon released from TRH. In general, estimated survival rates are consistent with an hypothesis that larger size at release results in greater survival rates. Across brood years, there was a relatively consistent pattern of largest survival rates for fish released at the largest size and lowest survival rates for fish released at the smallest size. Generally, survival rates for the smallest sized releases were about one half those for the largest sized fish released from the same brood year. We were unable to engage in any sophisticated analyses of these data, however, because we felt that such analysis would be unwarranted given the very large number of releases for which mean weights at release were not directly measured but were instead conjectured ("assumed") based on usual patterns of size across raceways as they reflect dates of parental spawnings.

Table 4.3. Estimated survival rates from release to age 2 for TRH fall Chinook salmon fingerlings released at different sizes, 1997 - 2001 brood years. Note that mean weights at release were not reported for all individual CWT release groups for the 1999, 2000 and 2001 brood years. See text for explanation of "assumed" values.

				Mean Weights (g)		
BY	Raceway	CWT Code	# Released	Reported	Assumed	$\hat{S}_0$
1997	C1/2	065236	48,381	5.15	5.15	0.0269
1997	C3/4	065235	49,785	4.54	4.54	0.0198
1997	D1/2	065234	49,353	4.20	4.20	0.0277
1997	D3/4	065233	50,927	4.12	4.12	0.0216
1997	E1/2?	065239	18,304	2.83	2.83	0.0222
1998	C1/2	065242	46,399	4.28	4.28	0.0062
1998	C3/4	065243	42,659	3.84	3.84	0.0055
1998	D1/2	065244	49,332	3.36	3.36	0.0039
1998	D3/4	065245	46,391	3.22	3.22	0.0034
1999	C1/2	065254	44,835	5.71	5.86	0.0231
1999	C3/4	065255	43,066	5.71	5.53	0.0124
1999	D1/2	065256	43,921	5.01	5.19	0.0154
1999	D3/4	065257	51,781	5.01	4.86	0.0142
2000	A1/2	065265	32,795	8.10	9.22	0.0329
2000	A1/2	065271	54,867	8.10	9.22	0.0370
2000	A1/2	065272	36,035	8.10	9.22	0.0303
2000	A3/4	065266	33,806	8.10	8.11	0.0277
2000	A3/4	065275	64,250	8.10	8.11	0.0232
2000	A3/4	065276	27,159	8.10	8.11	0.0335
2000	B1/2	065267	34,852	8.10	7.00	0.0283
2000	B1/2	065273	57,444	8.10	7.00	0.0273
2000	B1/2	065274	32,096	8.10	7.00	0.0286
2000	C1/2	065643	25,007	6.87	6.87	0.0306
2000	C3/4	065268	33,240	5.27	5.27	0.0136
2000	C3/4	065277	56,582	5.27	5.27	0.0145
2000	C3/4	065278	34,183	5.27	5.27	0.0154
2001	C1/2	065284	120,531	6.39	6.66	0.0032
2001	C3/4	065285	114,624	6.39	6.10	0.0031
2001	D1/2	065286	126,135	5.27	5.54	0.0038
2001	D3/4	065287	121,607	5.27	4.99	0.0032
2001	E3/4	065290	10,234	3.60	3.60	0.0013
2001	E3/4	066291	8,269	3.60	3.60	0.0014

IGH

Although IGH appears to have been using distinct CWT codes to tag fish reared in individual raceways since about the 1993 brood year, reported mean weights for multiple CWT release groups have almost always had the same value for multiple groups, ruling out any ability to evaluate the possible effect of size at release on survival rates of fish released as fingerlings from IGH.

4.2.3 Maturation Probabilities versus Release Type

Age-specific maturation probabilities were always lower for yearling than for fingerling release groups of fall and spring Chinook salmon from IGH and TRH, and mean age-specific maturation probabilities decreased with duration of rearing time prior to release for CRH spring Chinook salmon. Mean estimated age-specific maturation probabilities also were distinctive among stocks. For example, TRH fall Chinook salmon released as fingerlings or yearlings had a much greater tendency to mature at age 2 (mean $\sigma_{2F} = 0.1073$, mean $\sigma_{2Y} = 0.0409$) than did IGH fall Chinook salmon released as fingerlings or yearlings (mean $\sigma_{2F} = 0.0323$, mean $\sigma_{2Y} = 0.0089$). TRH spring Chinook salmon released as fingerlings or yearlings had lower age-specific maturation than did TRH fall Chinook salmon of the same release type. Age specific maturation probabilities were lowest for CRH spring Chinook salmon, especially at ages 3 and 4. Whereas all TRH and IGH stocks and release types had mean age 4 maturation probabilities that exceeded about 90%, mean age 4 maturation probabilities for CRH spring Chinook released from August through October ranged from about 70-80% and mean age 3 maturation probabilities ranged from about 6-12% (compare with 36% and 56% for TRH releases of yearling and fingerling spring Chinook salmon, Table 4.4).

4.2.4 Size at Age versus Release Type

For IGH and TRH fall and spring Chinook salmon, mean lengths at age of hatchery return were consistently larger for fish released as fingerlings than for fish released as yearlings, and mean lengths decreased with duration of rearing time prior to release for CRH spring Chinook salmon. Effects were large at age 2, modest at age 3, and generally very small by age 4. As for maturation probabilities, distinct differences were noted across stocks. for example, at ages 2 and 3, IGH fall Chinook averaged about 30 mm longer than TRH fall Chinook, and lengths at age 4 for CRH spring Chinook (762 - 785 mm for October - August releases) were considerably larger than for TRH spring Chinook (750 mm for fingerlings and 732 mm for yearlings). No attempt was made to statistically test for differences between means, in part because such tests can only be meaningfully made by ensuring that brood years are identical for any given comparison. As noted in Table 4.5, numbers of brood years used to calculate the reported means for the various stocks and release types varied substantially, especially

Table 4.4. Mean estimated age-specific maturation probabilities for IGH and TRH fall Chinook salmon released as fingerlings (June) or yearlings (October), for TRH spring Chinook salmon released as fingerlings (June) or yearlings (October), and for CRH spring Chinook salmon released as subyearlings during August, September or October. Reported means are simple averages of pooled brood-year-specific estimates. Numbers and identities of brood years vary slightly across stock types.

Fall Chinook	IGH Fing.	TRH Fing.	IGH Year.	TRH Year.
Age 2	0.0323	0.1073	0.0089	0.0409
Age 3	0.4700	0.6336	0.2245	0.5586
Age 4	0.9341	0.9303	0.9374	0.9408

Spring Chinook	TRH Fing.	CRH Aug.	CRH Sep.	CRH Oct.	TRH Year.
Age 2	0.0397	0.0263	0.0150	0.0129	0.0217
Age 3	0.5872	0.1168	0.0761	0.0613	0.3619
Age 4	0.9583	0.8025	0.7271	0.7052	0.8971

for lengths at age 2. Age 2 maturation probabilities were sufficiently low for some stocks and release types (e.g., CRH spring Chinook, IGH fall yearlings) that there were no reported hatchery lengths for some or many brood years.

4.3 Covariance Among Estimated Parameters Across Hatcheries and Races

All stocks showed striking interannual variation in survival rates from release to age 2, age-specific maturation probabilities, and size at age. In many cases, there was striking covariance between stocks in these attributes. Generally, covariance was strongest for between stocks released from the same hatchery at the same approximate date (e.g., TRH spring and fall Chinook released as fingerlings or as yearlings). Covariation between stocks was also quite strong for IGH and TRH fall Chinook released as fingerlings or yearlings. Survival rates of CRH October releases of subyearling spring Chinook showed less covariation with TRH spring Chinook releases, but covariation was still evident even though distance between the mouths of the Klamath and Rogue Rivers is considerable (about 70 miles).

Table 4.5. Mean lengths at age of hatchery return for IGH and TRH fall Chinook salmon released as fingerlings (June) or yearlings (October), for TRH spring Chinook salmon released as fingerlings (June) or yearlings (October), and for CRH spring Chinook salmon released as subyearlings during August, September or October. Reported means are simple averages of pooled brood-year-specific mean lengths. Numbers (in parentheses) and identities of brood years vary across stock types, especially at age 2.

Fall Chinook	IGH Fing.	TRH Fing.	IGH Year.	TRH Year.
Age 2	521.6 (15)	489.4 (21)	461.1 (14)	455.9 (23)
Age 3	690.4 (21)	659.5 (23)	646.2 (21)	631.9 (24)
Age 4	791.9 (21)	757.2 (22)	776.1 (21)	753.7 (24)

Spring Chinook	TRH Fing.	CRH Aug.	CRH Sep.	CRH Oct.	TRH Year.
Age 2	469.0 (18)	430.5 (11)	406.0 (06)	404.7 (07)	433.7 (21)
Age 3	658.6 (19)	654.5 (15)	632.5 (13)	607.4 (14)	616.4 (22)
Age 4	750.4 (19)	785.4 (16)	772.1 (17)	762.4 (19)	731.8 (22)

4.3.1 Survival Rates

In this section, we present an example of interannual variation in survival rates of fingerlings as compared to yearlings from the same stock type, but we focus our attention primarily on covariation between estimates of survival rates for the same release type but from different stocks. We begin with the strongest detected covariation (spring and fall stocks of Chinook salmon released from TRH), and then examine variation between estimated survival rates of stocks within the same system (fall Chinook released from IGH and TRH), and we conclude with a comparison of survival rates of CRH and TRH spring Chinook salmon released as subyearlings in October (termed “yearlings” in CA).

Fingerlings vs Yearlings

Survival rates of yearlings exceeded survival rates of fingerlings in almost all years for all stocks, but in a small number of instances survival rates of fish released as fingerlings in June were comparable to or slightly exceeded survival rates of fish released in October as yearlings. We used a log transformation of mean brood-year specific survival rates to evaluation correlations across years, as adopted in the recent stock-recruitment analysis of Klamath River Chinook salmon (STT 2005). Correlations between these log-transformed mean survival rates of fish released as fingerlings or yearlings from the same brood year were generally not strong. We present only one illustrative example, Iron Gate fall Chinook salmon (Figure 4.2). Correlations between survival rates of fish from different stocks released at the same approximate time (e.g., fingerling fall Chinook from IGH and TRH) were highly significant, however, and are discussed below. In most cases we present figures to visually illustrate the covariation because these are in many cases very striking.

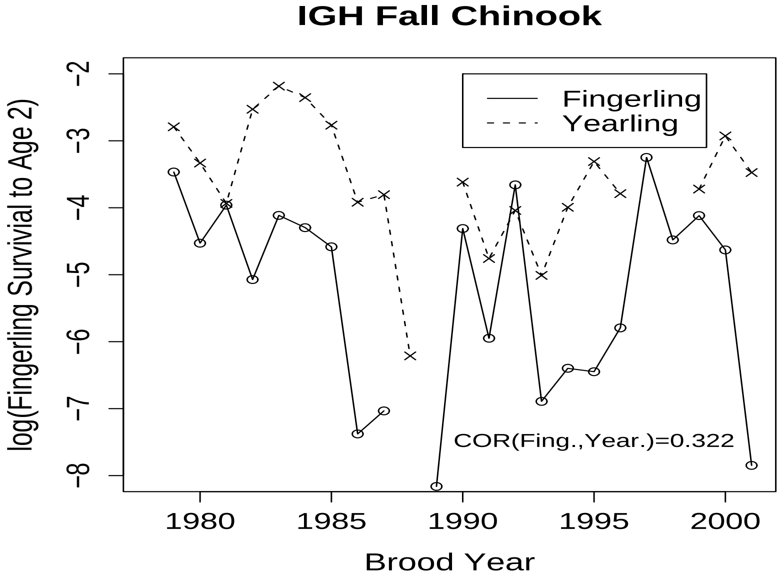


Figure 4.2. Estimated brood year-specific log-transformed mean survival rates from release to age 2 for IGH releases of fall Chinook salmon as fingerlings (June) or yearlings (October), 1978-2001 brood years.

Although CRH released no Rogue spring Chinook salmon as fingerlings, it was possible to compare survival rates for fish released from the same brood years in the months of August, September or October (Figure 4.3). Correlations between log-transformed mean survival rates across brood years were very high for August compared to September releases ($r = 0.851$), but were less substantial for comparisons of August with October ($r = 0.620$) or September with October ($r = 0.544$).

TRH Fall vs Spring Chinook

The strongest degree of interannual covariation in log-transformed mean survival rates was seen in comparisons of survival rates of fingerlings and yearlings for fall and spring Chinook salmon released from TRH. Calculated correlations between log-transformed survival rates of fall and spring Chinook released from TRH were extremely high: 0.869 for fingerlings (Figure 4.4) and 0.912 for yearlings (Figure 4.5).

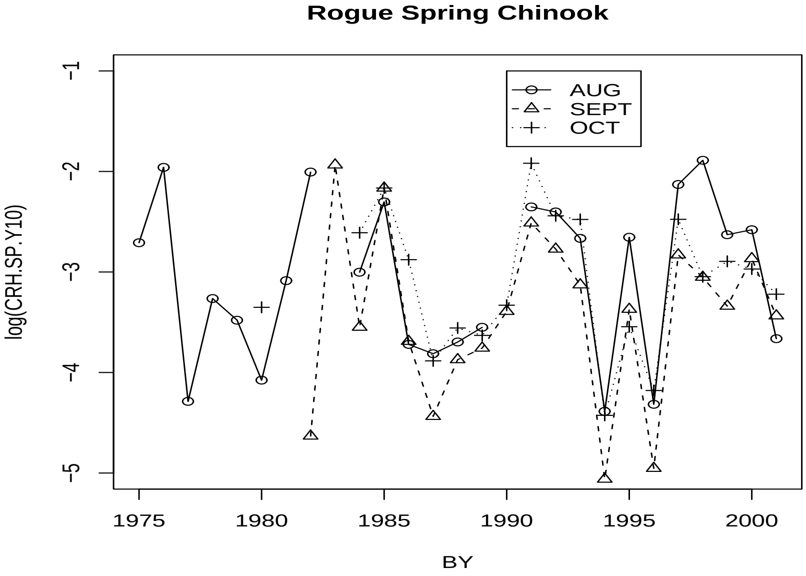


Figure 4.3. Estimated brood year-specific mean log-transformed survival rates from release to age 2 for CRH releases of spring Chinook salmon in August, September or October, 1975-2001 brood years.

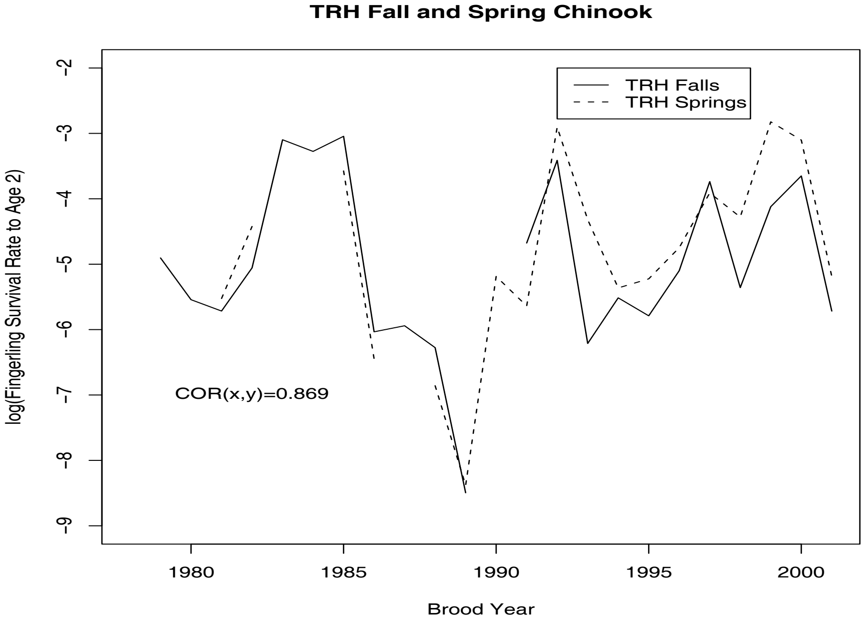


Figure 4.4. Estimated brood year-specific log-transformed mean survival rates from release to age 2 for TRH releases of fingerling fall and spring Chinook salmon, 1979-2001 brood years.

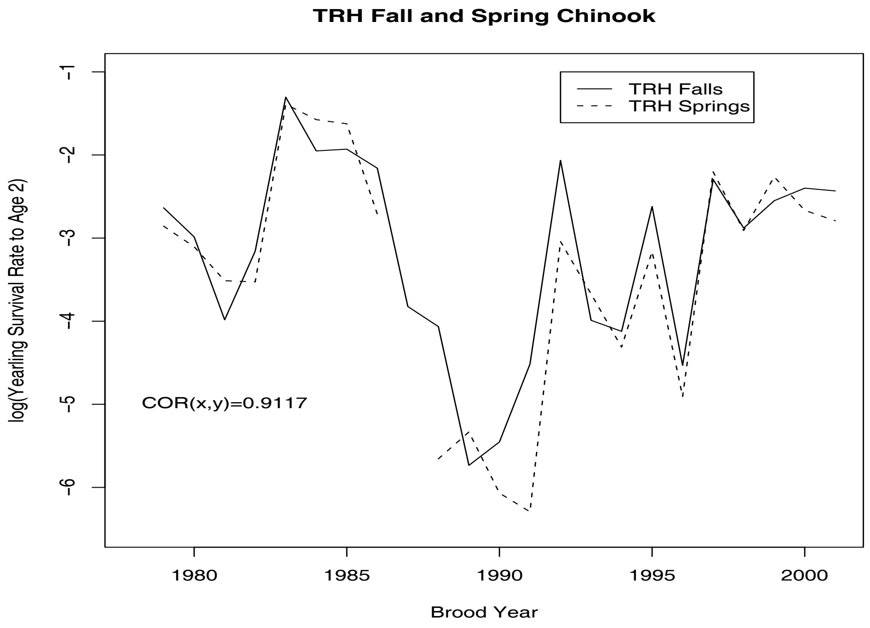


Figure 4.5. Estimated brood year-specific log-transformed mean survival rates from release to age 2 for TRH releases of yearling fall and spring Chinook salmon, 1979-2001 brood years.

IGH vs TRH Fall Chinook

Although not as highly correlated as survival rates between releases of the same type for different races of Chinook reared at TRH, log-transformed survival rates for fall Chinook released as fingerlings from TRH were nevertheless very highly correlated with those for fingerlings released from IGH ($r = 0.757$, Figure 4.6), and log-transformed survival rates were also highly correlated for yearlings released from the two Klamath system hatcheries ($r = 0.582$, Figure 4.7). We saw no clear evidence that relative survival rates of IGH fall Chinook compared to TRH fall Chinook have decreased over the past decade or so due to changes in water management policies in the upper Klamath River. Indeed, mean survival rates for fingerlings released from IGH actually exceeded those for fingerlings released from TRH for the 1997 and 1998 brood years, a relatively unusually situation when compared to the complete time series of survival rates (see Figure 4.6). Survival rates of IGH fingerlings are typically lower than for TRH fingerlings released from the same brood year.

TRH vs CRH Spring Chinook

Covariation of log-transformed mean survival rates from release to age 2 was less striking for October releases of spring Chinook from CRH as compared to TRH (yearlings). The correlation over the entire data set was just 0.322, considerably less than for other between stock or between hatchery calculations, but this correlation was heavily influenced by the 1991 brood year for which survival rates of CRH CWT

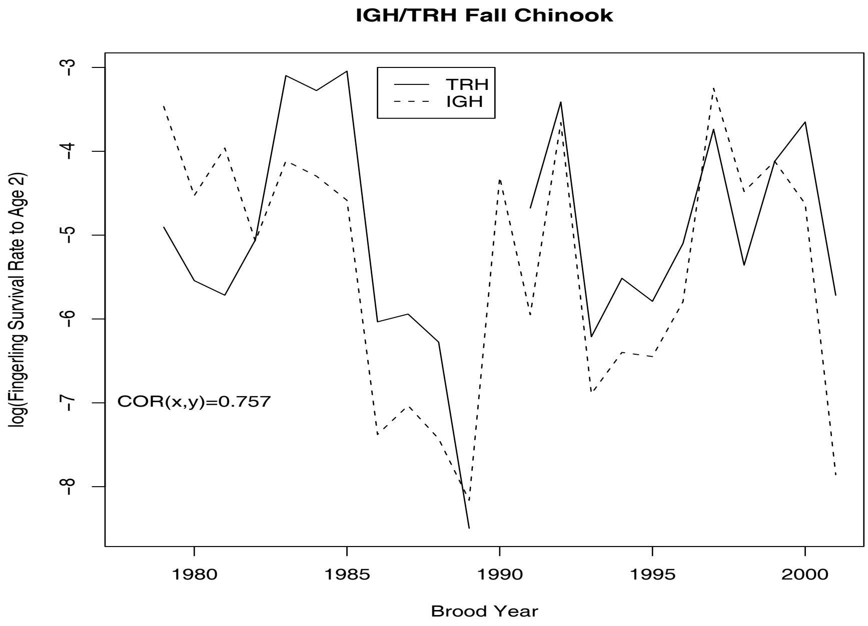


Figure 4.6. Estimated brood year-specific log-transformed mean survival rates from release to age 2 for TRH and IGH releases of fingerling fall Chinook salmon, 1979-2001 brood years.

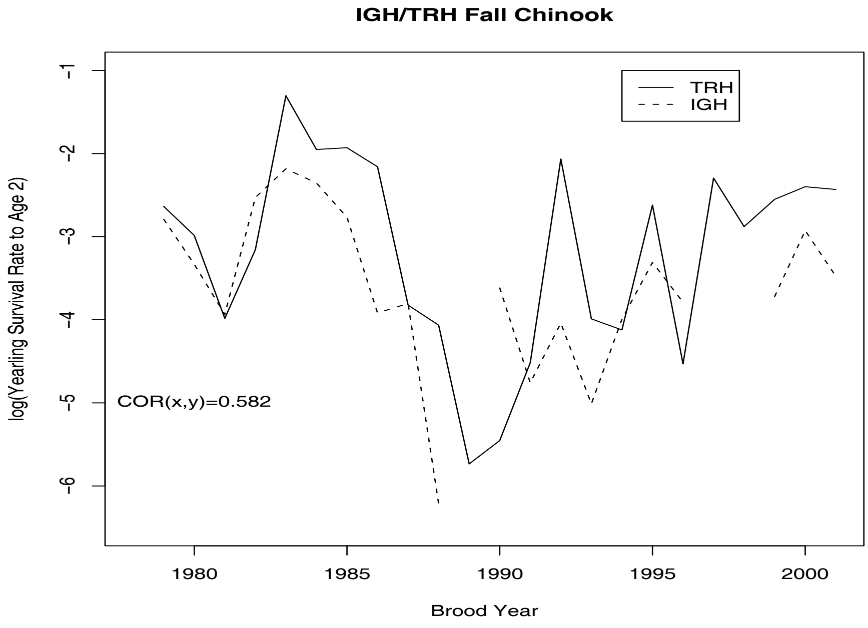


Figure 4.7. Estimated brood year-specific log-transformed mean survival rates from release to age 2 for TRH and IGH releases of yearling fall Chinook salmon, 1979-2001 brood years.

groups were quite good (0.095) but for which survival rates of TRH CWT groups was exceptionally poor (0.0118, see Figure 4.8). With the 1991 data point removed, the correlation improved to 0.515, similar to the calculated correlation between yearling releases of fall Chinook salmon made from IGH and TRH (0.582).

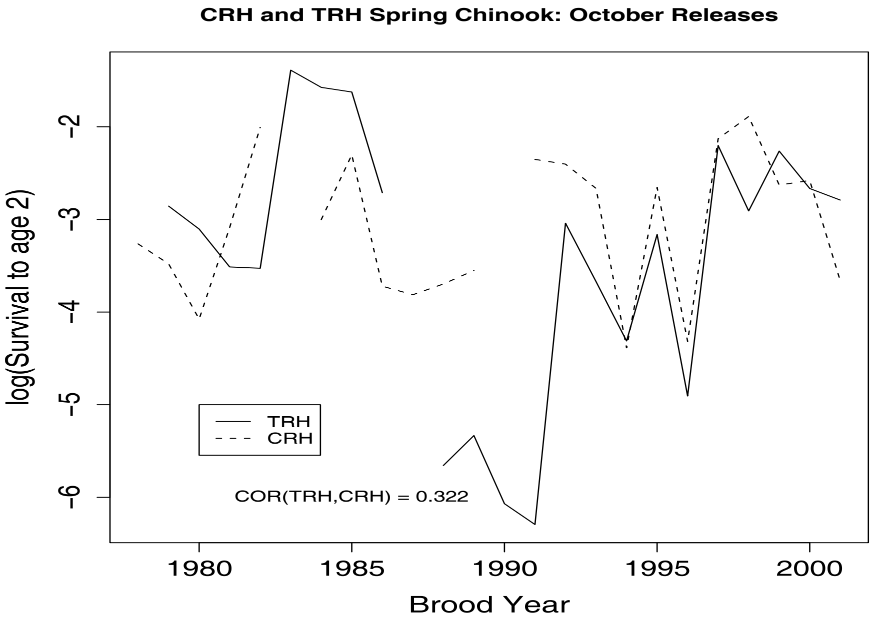


Figure 4.8. Estimated brood year-specific log-transformed mean survival rates from release to age 2 for TRH and CRH releases of spring Chinook salmon in October, 1979-2001 brood years.

4.3.2 Maturation Probabilities

Maturation probabilities often displayed striking covariation across stocks and hatcheries. Similar to covariation in survival rates, we found strongest covariation in maturation probabilities between stocks released from the same hatchery. We present only two visually striking graphical examples of such covariation from the many comparisons that were made, but we provide a summary table that reports all calculated correlations.

The most striking examples of covariation of maturation probabilities were for comparisons of age 2 and age 3 maturation probabilities for TRH fall Chinook salmon released as fingerlings compared to yearlings (r = 0.819 and r = 0.807, respectively) and for comparisons of age 2 and age 3 maturation probabilities of CRH spring Chinook released in August, September or October. For example, Figure 4.9 displays age 2 maturation probabilities for TRH fall Chinook released as fingerlings as compared to yearlings. In addition to illustrating the strong covariation in estimated maturation probabilities for the two release types, this figure also suggests a possible long-term trend to lower age 2 maturation probabilities.

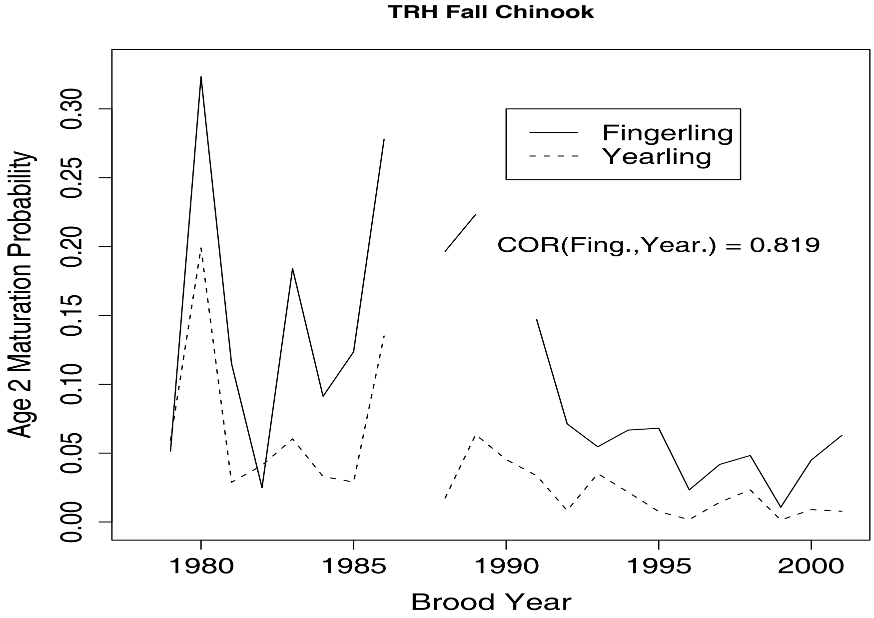


Figure 4.9. Estimated brood year-specific age 2 maturation probabilities for TRH fall Chinook salmon released as fingerlings (June) or as yearlings (October), 1979-2001 brood years.

Covariation of age 2 and age 3 maturation probabilities of Rogue spring Chinook released in August, September and October was even stronger than those for TRH fingerlings and yearlings. These correlations ranged from 0.751 (age 3 maturation probabilities for August vs October releases) to 0.984 (age 2 maturation probabilities for August vs October releases, see Figure 4.10) and exceeded 0.920 in 5 of 6 comparisons. Correlations for all calculated comparisons are presented in Table 4.6.

4.3.3 Size at Age

Interannual variation in size at age (measured by size of fish at return to hatcheries) was substantial across all stocks and races and there was striking covariation in size at age across all stocks and races. For illustrative purposes, we focus on comparisons between the most similar stocks (TRH fall and spring Chinook), similar stocks released from different hatcheries (IGH vs TRH fall Chinook) and the most dissimilar stocks (TRH and CRH spring Chinook).

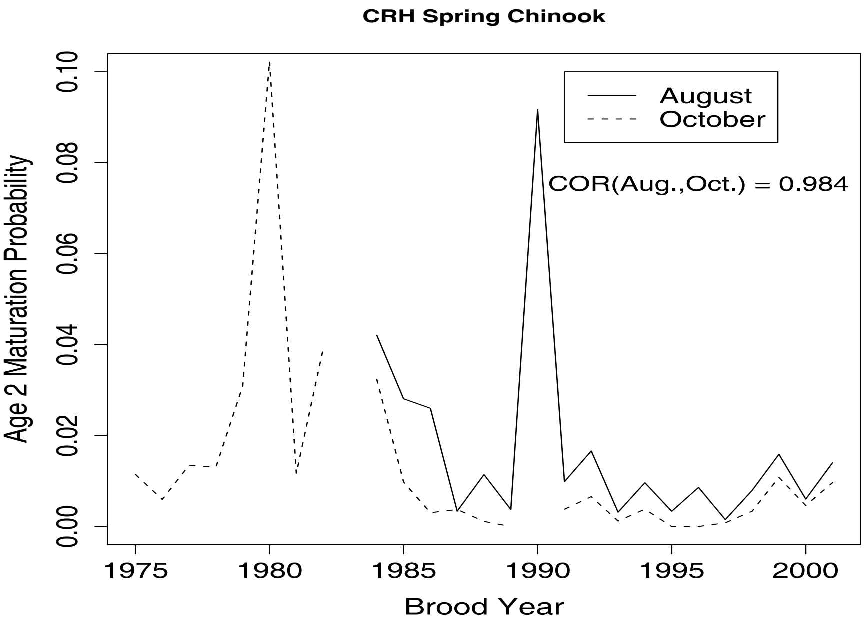


Figure 4.10. Estimated brood year-specific age 2 maturation probabilities for CRH fall Chinook salmon released as subyearlings in August as compared to October, 1975-2001 brood years.

TRH Fall vs Spring Chinook Released as Fingerlings

Spring and fall Chinook reared and released from TRH as fingerlings share essentially identical rearing and release history and are very closely related from a genetic perspective. It would therefore be reasonable to suppose that lengths at age for these two stock types would be most highly correlated. As Figure 4.11 illustrates, lengths at age are indeed very highly correlated for these two populations.

IGH vs TRH Fall Chinook Released as Fingerlings

Although IGH and TRH fall Chinook are genetically distinct and experience different rearing and downstream migration histories, fingerlings from the two hatcheries are released at a similar time (early June) and should theoretically experience very similar ocean growing conditions. Therefore, it would be reasonable, *a priori,* to assume that lengths at age would be highly correlated between these two stocks from the Klamath River. As Figure 4.12 illustrates, size at age for these two stocks clearly covary in a striking fashion, with fish from IGH typically larger than those from TRH.

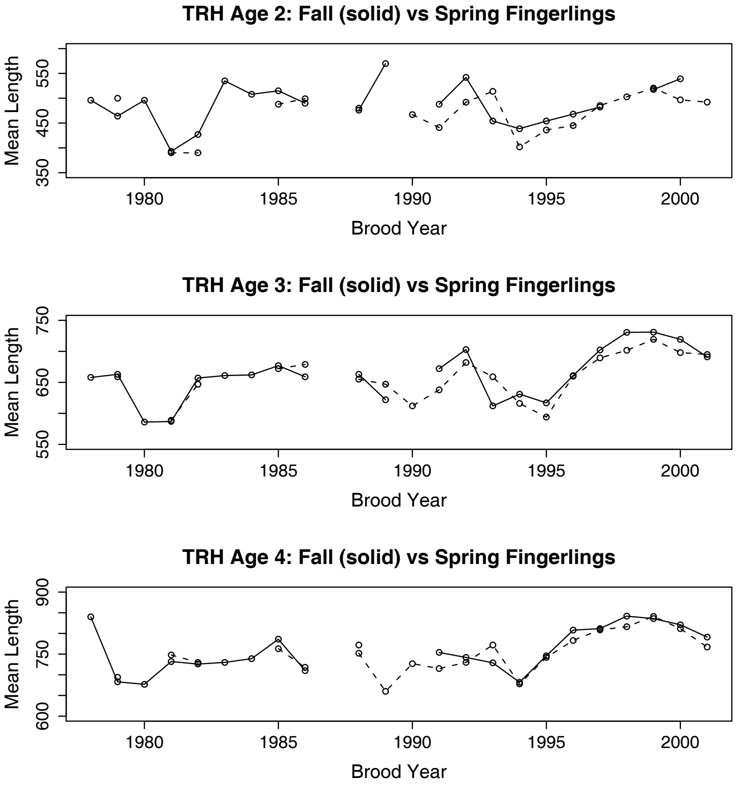
TRH vs CRH Spring Chinook released as Yearlings

TRH and CRH spring Chinook stocks are the most genetically distinct stocks considered in this report, do not share rearing or downstream migration histories,

Table 4.6. Calculated correlations between stocks and/or release types for estimated age 2 and age 3 maturations

Maturation Probability	Comparison	Correlation	Sample Size
σ_2	IGH vs TRH Fingerlings	0.679	20
σ_3	IGH vs TRH Fingerlings	0.093	20
σ_2	IGH vs TRH Yearlings	0.367	19
σ_3	IGH vs TRH Yearlings	0.351	19
σ_2	IGH Fall: Fing. vs Year.	0.573	19
σ_3	IGH Fall: Fing. vs Year.	0.417	19
σ_2	TRH Fall: Fing. vs Year.	0.819	21
σ_3	TRH Fall: Fing. vs Year.	0.807	21
σ_2	TRH Spring: Fing. vs Year.	-0.079	21
σ_3	TRH Spring: Fing. vs Year.	0.516	21
σ_2	CRH Spring: Aug. vs Sept.	0.966	17
σ_2	CRH Spring: Aug. vs Oct.	0.984	17
σ_2	CRH Spring: Sept vs Oct.	0.950	18
σ_3	CRH Spring: Aug. vs Sept.	0.920	18
σ_3	CRH Spring: Aug. vs Oct.	0.751	17
σ_3	CRH Spring: Sept vs Oct.	0.926	18

and their release locations are most distant from one another among those stocks considered in this report. Therefore, *a priori,* one might suspect that lengths at age would covary less strongly than for the previous two comparisons. As Figure 4.13 illustrates, however, lengths at age for October releases from these two stocks also exhibit striking interannual covariation. This strong degree of covariation presumably is a reflection of the fact that the two stocks experience very similar ocean growing conditions during their lives, probably also suggesting that the two stocks may share very similar ocean migration patterns.


TRH Age 2: Fall (solid) vs Spring Fingerlings

TRH Age 3: Fall (solid) vs Spring Fingerlings

TRH Age 4: Fall (solid) vs Spring Fingerlings

Figure 4.11. Mean lengths at age (measured at hatchery return) for spring and fall Chinook salmon released from Trinity River Hatchery as fingerlings, 1975-2001 brood years.

4.4 Simulated Cohort Analysis Estimator Performance versus CWT Release Group Size

Results of simulations (based on IGH fingerling releases, see Table 4.11) for release groups sizes (R) of 25K, 50K, 100K, 200K, and 400K, showed that cohort analysis estimators of model parameters were asymptotically approximately unbiased; small positive bias seemed evident for some model parameters, especially for $E_{4.pos}$, but positive bias for other model parameters was generally modest and negligible so long as release group size was about 100K. Thus, with the exception of $E_{4.pos}$, selection of release group size should not be strongly influenced by bias considerations.

Simulated coefficients of variation (CV), however, varied considerably across model parameters. The most poorly behaved parameters were the post-maturation exploitation rates, $E_{3.pre}$ and $E_{3.pos}$, for which CV exceeded 200% for $R = 25K$ and for which CV exceed 50% even for $R = 400K$. Parameters with intermediate behavior included the two pre-maturation exploitation rates, $E_{3.pre}$ and $E_{4.pre}$, and the age 2 maturation

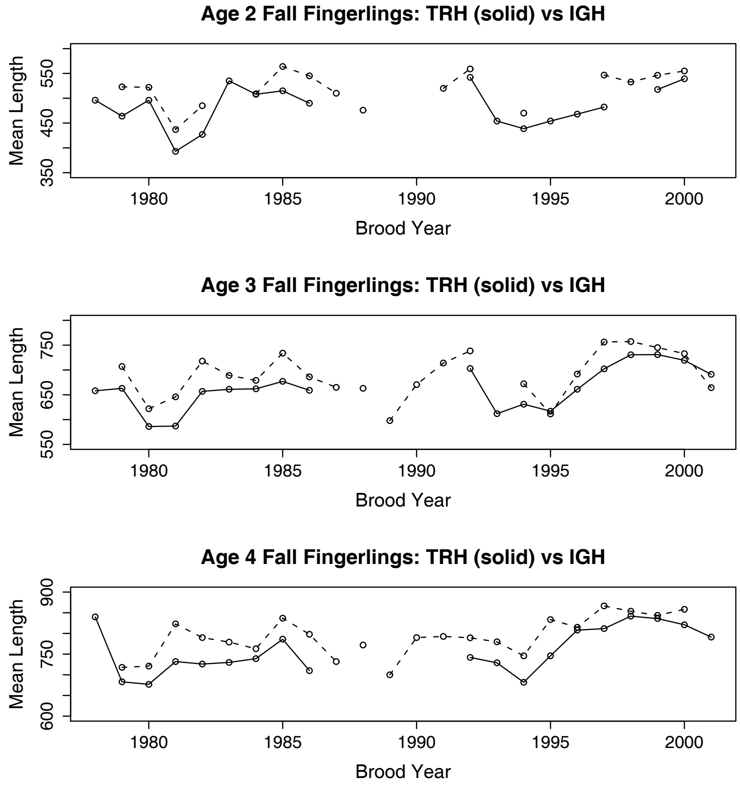


Figure 4.12. Mean lengths at age (measured at hatchery return) for fall Chinook salmon released as fingerlings from IGH and TRH, 1978-2001 brood years.

parameter, σ_2. For these parameters, CV ranged from 76-97% for $R = 25K$, but then decreased to from 19-24% at $R = 400K$. Estimators of the remaining parameters, σ_3, σ_4 and S_0, were well-behaved, even for small release groups sizes. For these parameters, CV ranged from 11-30% at $R = 25K$ and decreased to from 3-7% at $R = 400K$ (Table 4.7).

As a rough rule of thumb for fishery management, it is desirable that CV for estimated parameters is not much more than 25%. On that basis, it seems that $R = 200K$ or perhaps slightly larger (250K?) would be a wise choice of release group size given the level of ocean exploitation that has been typical over the past 10-15 years. This would give CV less than 30% for the critical pre-maturation exploitation rates, about 33% for the age 2 maturation parameter, and no more than 10% for the remaining maturation parameters and for survival rate to age 2. This release group size would not be large enough to allow accurate estimation of the post-maturation exploitation rates at ages 3 or 4, however. Estimation of $E_{4.pos}$ is especially problematic because essentially all Klamath river Chinook mature at age 4; thus, few should remain available to potential ocean capture in the post-maturation ocean fishery.

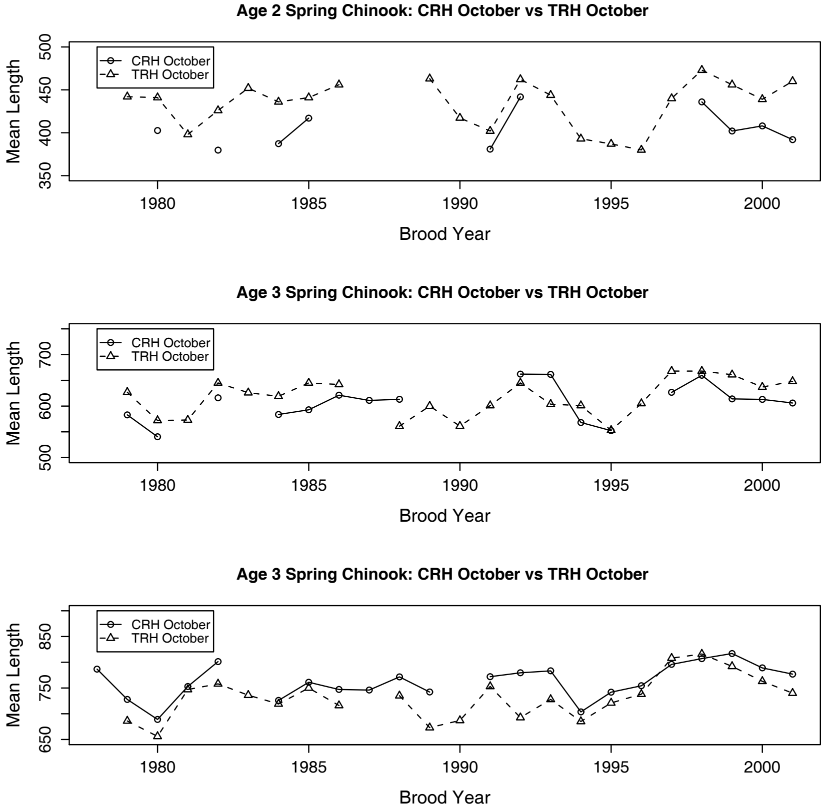


Figure 4.13. Mean lengths at age (measured at hatchery return) for spring Chinook salmon released as subyearlings in October from TRH and CRH, 1978-2001 brood years.

4.5 Survival Rates versus Flow - IGH and TRH

A plot of mean annual flows for the month of June at the Seiad gauge against estimated mean annual survival rates for IGH releases of fingerling fall Chinook salmon (Figure 4.14) suggested a highly non-random association of survival rates and flow and, among other things, implies that survival rates are generally high when fish are released under high flows.

A similar plot of estimated mean annual survival rates for TRH releases of fingerling Chinook salmon again mean June flows at Burnt Ranch failed to suggest any relation between survival and Trinity River flows (Figure 4.15), however, although June flows at the two locations were highly correlated with one another (r=0.868, see Figure 4.16).

Our tentative conclusion that survival rates may be affected by river flow following release rests strongly on an observation that the four highest flows are associated with generally high survival rates; at much lower flows variation in survival rates is large

Table 4.7. Simulated expected values and coefficients of variation (standard deviation/expected value) of parameters estimated from cohort analyses as a function of release group size (R = 25K, 50K, 100K, 200K, 400K). Assumes that age 2 ocean impact rates are 0. Based on multinomial model for fates of released fish, Poisson model for 20% level of sampling, and 100,000 independent simulations for each release group size.

		Expected Values				
Parameter	True Value	25K	50K	100K	200K	400K
$E_{3.pre}$	0.0852	0.0861	0.0851	0.0858	0.0853	0.0852
$E_{3.pos}$	0.0208	0.0214	0.0216	0.0211	0.0210	0.0208
$E_{4.pre}$	0.1579	0.1595	0.1578	0.1582	0.1572	0.1575
$E_{4.pos}$	0.0755	0.0945	0.0874	0.0869	0.0810	0.0800
σ_2	0.0286	0.0299	0.0291	0.0290	0.0287	0.0288
σ_3	0.4219	0.4246	0.4248	0.4216	0.4219	0.4227
σ_4	0.9345	0.9364	0.9358	0.9353	0.9345	0.9344
S_0	0.0097	0.0097	0.0097	0.0097	0.0097	0.0097

	Coefficients of Variation				
Parameter	25K	50K	100K	200K	400K
$E_{3.pre}$	0.7611	0.5378	0.3747	0.2630	0.1867
$E_{3.pos}$	2.2651	1.5577	1.0748	0.7457	0.5374
$E_{4.pre}$	0.8516	0.5967	0.4118	0.2897	0.2047
$E_{4.pos}$	2.9394	2.9217	2.6221	2.0958	1.4340
σ_2	0.9660	0.6714	0.4659	0.3308	0.2367
σ_3	0.2999	0.2086	0.1474	0.1015	0.0721
σ_4	0.1138	0.0795	0.0558	0.0392	0.0280
S_0	0.2340	0.1671	0.1177	0.0840	0.0584

and the mean survival rate is considerable lower. Because our tentative conclusion really rests on the location of just four data points, we used a Monte Carlo permutation test (see, e.g., Good 2005) to calculate the probable statistical significance of this conclusion.

We calculated the probability that the relatively high survival rates would be associated with the four highest flows under a null hypothesis that survival rates and flows were completely uncorrelated with one another. To accomplish this test, we made a large number (40,000) of independent, random rearrangements of the times series of flows and survival rates. For each such pair of random rearrangements, we calculated the difference between the mean survival rate (or log(mean survival rate)) associated with the four highest flows and the mean survival rate associated with the remaining flows. We then calculated the probability of observing a difference as large or larger

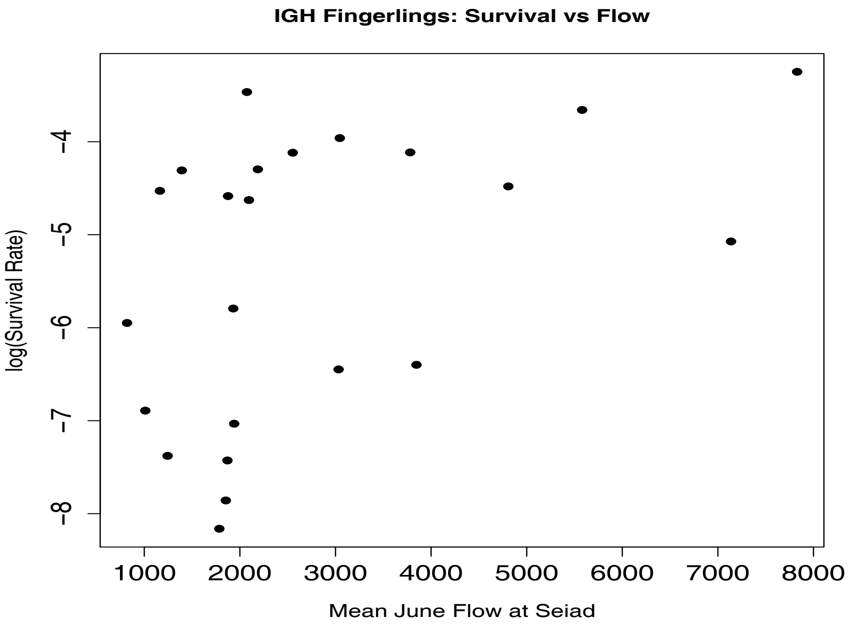


Figure 4.14. Estimated brood year-specific mean survival rates from release to age 2 for IGH releases of fingerling fall Chinook salmon (released in early June) plotted against mean June flow at Seiad.

than the actual difference implied by Figure 4.14. We found that the probability of finding differences as large as those observed were about 0.027 and 0.029, respectively, for the differences between mean survival rates and log(mean survival rates)(see Figure 4.17). We conclude that there is substantial, although not convincing, reason to reject the null hypothesis that flows and survival rates are uncorrelated. Therefore, we continue to suspect that survival rates of IGH fall Chinook salmon are positively associated with flows in the upper Klamath River following release.

4.6 Alternative Mixes of Fingerling and Yearling Releases

4.6.1 Trinity River Hatchery

As noted previously, production goals for fall Chinook salmon at TRH are 2.00 million fingerlings, released in early June, and 0.90 million yearlings, released in early October. Values used to characterize life history and fishery model parameters for TRH fingerlings and yearlings are summarized in Table 4.8.

We used the mean parameter values from Table 4.8 to calculate expected age-

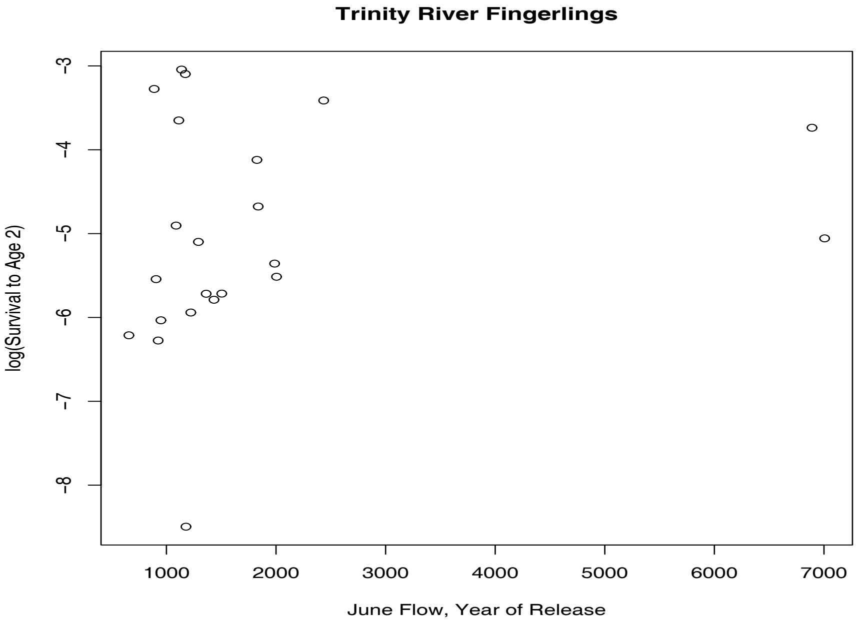


Figure 4.15. Estimated brood year-specific mean survival rates from release to age 2 for TRH releases of fingerling fall Chinook salmon (released in early June) plotted against mean June flow at Burnt Ranch.

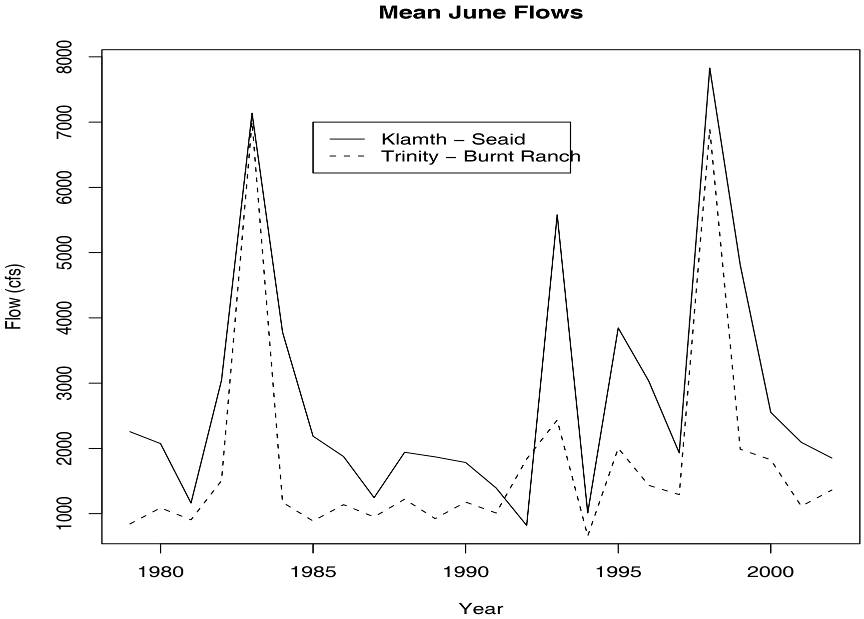


Figure 4.16. Mean June flows at Seaid (Klamath River) and Burnt Ranch (Trinity River) USGS gauges, release years 1979-2002.

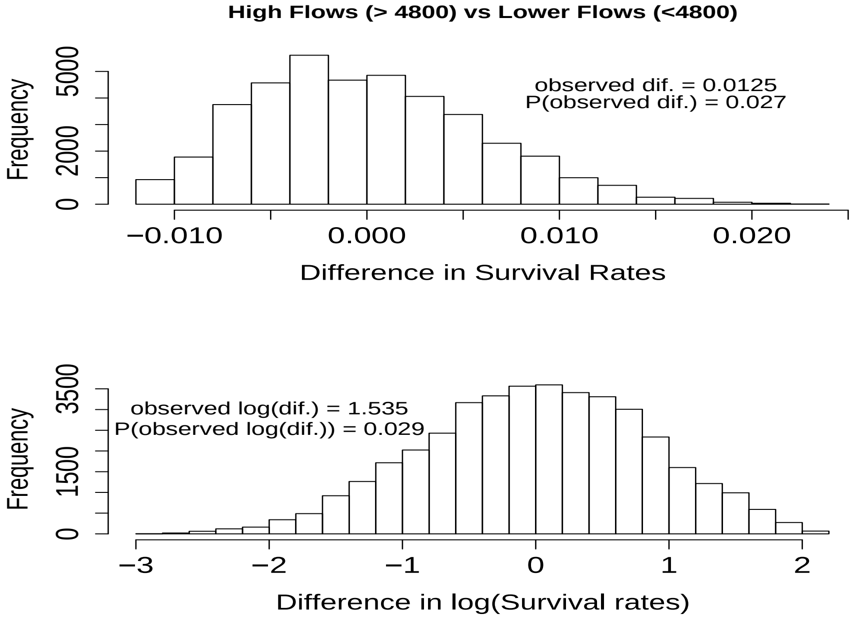


Figure 4.17. Simulated differences between the mean survival rates (or log(survival rates)) associated with the four highest June flows at Seiad and the mean survival rates associated with lower flows, under a null hypothesis that flows and survival rates are uncorrelated.

specific ocean impacts (catches + non-landed mortalities) prior to (OCN.pre) and after (OCN.post) maturation; expected age-specific freshwater catches (FW.Catch); and expected age-specific freshwater escapements from fingerling (*.F) or yearling (*.Y) releases given a specified mixture of releases. Table 4.9 shows the expected adult (age 3 and older) contributions (numbers of fish) from fingerlings and yearlings for the current TRH production releases consisting of 2.00 million fingerlings and 0.90 million yearlings.

We also calculated a proxy for contributions of fish in terms of biomass by multiplying expected numerical contributions by the cube of the corresponding length at age and scaling by a factor of 10^{-8}. Expected combined (fingerling + yearling) contributions, expressed by numbers of fish and by biomass proxy, for different mixtures of fingerling and yearling releases are summarized in Table 4.10.

4.6.2 Iron Gate Hatchery

Mean parameter values used in calculations of expected contributions from alternative mixtures of releases of fingerling and yearling fall Chinook salmon from Iron Gate Hatchery are listed in Table 4.11. Summarized expected combined (fingerling + yearling) contributions given different mixtures of fingerling and yearling releases from IGH are presented in Table 4.12.

Table 4.8. Mean parameter values estimated from CWT recoveries of fingerling and yearling fall Chinook salmon released from Trinity River Hatchery: 1978-2001 BYs (life history parameters) and 1990-2001 BYs (fishery parameters).

Parameter	Fingerlings	Yearlings
Survival to Age 2	0.0146	0.0807
σ_2	0.0989	0.0386
σ_3	0.6257	0.5609
σ_4	0.9483	0.9770
$E_{2.pre}$	0.0000	0.0000
$E_{2.pos}$	0.0000	0.0000
$E_{3.pre}$	0.1009	0.0604
$E_{3.pos}$	0.0111	0.0051
$E_{4.pre}$	0.1896	0.1873
$E_{4.pos}$	0.0248	0.0337
$E_{5.pre}$	0.0292	0.0292
u_3	0.1585	0.1137
u_4	0.2559	0.2244
u_5	0.2402	0.2402
$\bar{l}_2$ (mm)	489.4	455.9
$\bar{l}_3$ (mm)	659.5	631.9
$\bar{l}_4$ (mm)	757.2	753.7
$\bar{l}_5$ (mm)	850.0	850.0

Table 4.9. Expected age-specific ocean impacts, freshwater catches, and spawning escapements for current TRH production releases of 2.00 million fingerlings (*.F) and 0.900 million yearlings (*.Y).

Age	OCN.pre.F	OCN.pos.F	FW.Catch.F	Escape.F
3	1,327	49	1,173	7,401
4	664	4	689	2,691
5	22	0	22	93
Totals	2,013	53	1,884	10,185
Age	OCN.pre.Y	OCN.pos.Y	FW.Catch.Y	Escape.Y
3	794	76	3,033	19,133
4	2,233	7	2,422	9,465
5	32	0	34	140
Totals	3,059	83	5,489	28,738

Table 4.10. Expected total age-specific ocean impacts, freshwater catches, and spawning escapements, expressed as numbers of adults (age 3 and older) or by associated biomass proxies, for different mixtures of fingerling and yearling releases of fall Chinook salmon from Trinity River Hatchery.

Number Released ($x10^6$)		Number of Age 3 and Older Adults			
Fingerlings	Yearlings	OCN Impacts	FW Catch	Escape.	Total
2.000	0.900	5,209	7,372	31,550	44,131
1.750	0.945	4,978	7,433	31,770	44,182
1.500	0.990	4,748	7,495	31,989	44,232
1.250	1.036	4,520	7,562	32,235	44,318
1.000	1.081	4,290	7,623	32,455	44,368
Number Released ($x10^6$)		Biomass (Proxy): Age 3 and Older			
2.000	0.900	20,824	27,007	111,351	159,182
1.750	0.945	20,147	27,152	111,897	159,197
1.500	0.990	19,471	27,297	112,444	159,211
1.250	1.036	18,807	27,464	113,081	159,352
1.000	1.081	18,130	27,609	113,628	159,366

Table 4.11. Mean parameter values estimated from CWT recoveries of fingerling and yearling fall Chinook salmon released from Iron Gate Hatchery: 1978-2001 BYs (life history parameters) and 1990-2001 BYs (fishery parameters). We assume no age 2 ocean impacts.

Parameter	Fingerlings	Yearlings
Survival to Age 2	0.0097	0.0397
σ_2	0.0286	0.0008
σ_3	0.4219	0.2174
σ_4	0.9345	0.9328
$E_{3.pre}$	0.0852	0.0333
$E_{3.pos}$	0.0208	0.0067
$E_{4.pre}$	0.1579	0.1768
$E_{4.pos}$	0.0755	0.0838
$E_{5.pre}$	0.1673	0.1673
u_3	0.1245	0.1260
u_4	0.3065	0.3567
u_5	0.3316	0.3316
$\bar{l}_2$ (mm)	528.4	475.3
$\bar{l}_3$ (mm)	688.1	648.3
$\bar{l}_4$ (mm)	789.4	774.1
$\bar{l}_5$ (mm)	850.0	850.0

Table 4.12. Expected total age-specific ocean impacts, freshwater catches, and spawning escapements, expressed as numbers of adults (age 3 and older) or by associated biomass proxies, for different mixtures of fingerling and yearling releases of fall Chinook salmon from Iron Gate Hatchery.

Number Released ($\times 10^6$)		Number of Age 3 and Older Adults			
Fingerlings	Yearlings	OCN Impacts	FW Catch	Escape.	Total
4.920	0.900	6,703	6,605	22,401	35,710
4.500	1.002	6,562	6,677	22,376	35,615
4.000	1.125	6,397	6,768	22,363	35,538
3.500	1.247	6,231	6,856	22,339	35,425
3.000	1.370	6,066	6,947	22,326	35,338
Number Released ($\times 10^6$)		Biomass (Proxy): Age 3 and Older			
4.920	0.900	26,973	29,166	87,062	143,201
4.500	1.002	26,649	29,470	86,760	142,879
4.000	1.125	26,281	29,857	86,464	142,601
3.500	1.247	25,901	30,228	86,127	142,256
3.000	1.370	25,533	30,614	85,830	141,977

Chapter 5

Discussion

Analyses of the approximately 25 years of CWT recovery data for spring and fall Chinook salmon released from IGH, TRH and CRH have strongly confirmed the conjectures made by Hankin (1990). Namely, release of Chinook salmon at a larger size (e.g., 40-50g vs 4-5 g) in a later month (e.g., October vs June) leads to (a) substantially improved survival to age 2 (an average of 400-500% improvement); (b) substantially reduced size at ages 2 and 3; (c) reduced maturation probabilities at ages 2 and 3; and (c) reduced age 3 ocean fishery exploitation rates. For TRH and IGH fall Chinook stocks, sizes of fingerlings and yearlings are similar at age 4, as are ocean fishery exploitation rates and age-specific maturation probabilities. For spring Chinook salmon from TRH and CRH, however, reductions in size at age and maturation probabilities were still evident at age 4 for fish released in a later month. We surmise that these differences in life history parameters are a direct reflection of the duration of ocean growth prior to maturation for fingerling (longer) as compared to yearling (shorter) releases and they are broadly consistent with an hypothesis that, for a given stock, size at age is an important factor influencing age at maturity (see Hankin et al. 1993.). It seems clear, however, that factors influencing maturation at age depend upon more than size at age. Although we certainly searched hard to find them, we did not detect any relationships suggesting a strong correlation between estimated age-specific maturation probabilities and size at age for specific release types from individual stocks. Wells et al. (2007) argue that maturation at age is correlated with growth rate at age rather than size at age per se, an attribute for which CWT recovery data do not provide a clear proxy.

Although we found no variable that was clearly correlated with age-specific maturation probabilities, we did note an apparent long-term decline in age 2 maturation probabilities of TRH fall Chinook released as fingerlings and yearlings (Figure 4.9) and we found that estimated mean age 4 maturation probabilities for IGH and TRH fall Chinook released as fingerlings or yearlings exceeded 94% (Table 4.4). The trend of decreasing age 2 maturation probabilities, if persistent, warrants further attention on two counts. First, it may reflect the long-term consequences of excluding or largely excluding jacks from matings (see Hankin, unpublished; Fitzgibbons 2004, Chen 2008), though this consequence is not necessarily undesirable. Second, the long-term pattern of decline in age 2 maturation probabilities among age 2 fingerling releases of fall Chinook, if shared by wild Klamath River Chinook, may complicate pre-season prediction of age 3 abundance of Klamath River Chinook based on returns of jacks in the preceding year. The exceptionally high age 4 maturation probabilities effectively mean that essentially no fall Chinook salmon reared at Klamath River hatcheries will return to freshwater as age 5 adult spawners. For example, assuming that a cohort has reached age 3 and is unexploited in the ocean, probabilities of maturing at ages 3, 4 and 5 can be calculated from the conditional age-specific maturation probabilities and ocean survival rate. For fingerling releases of Iron Gat fall Chinook salmon, such figures give the following probabilities: age 3 = 0.470 (= $\hat{\sigma}_3$); age 4 = 0.396 (= $(1-\hat{\sigma}_3)p_3\hat{\sigma}_4 = (1-.470)\cdot 0.8\cdot 0.934$); age 5 = 0.022 (= $1-\hat{\sigma}_3)p_3p_4(1-\hat{\sigma}_4)\sigma_5 = (1-.470)\cdot 0.8^2\cdot(1-0.934)\cdot 1$), where σ_5 is assumed equal to 1. These values generate unexploited age composition of adults that would be 52.9% age 3, 44.6% age 4, and just 2.5% age 5. Of course, Klamath fall Chinook are not unexploited in the ocean, and the effect of ocean fishing is to shift age structure toward younger ages (see Hankin and Healey 1986), thereby making it even less likely that any IGH fingerling fall Chinook will ever return to freshwater at age 5.

Analyses presented in this report are of a very preliminary nature, and we hope to engage in additional analysis if time and further funding permit. We believe that there is substantial potential for additional important insights to be gleaned from more sophisticated analysis of these CWT recovery data. Given the long-term commitment to rigorous sampling programs in ocean and freshwater for Klamath River Chinook salmon, the CWT recovery data examined in this report are of exceptionally high quality and certainly merit further analysis. In particular, we believe that there are two key features or improvements of additional analyses that would be highly informative. Fist, we believe that it is essential to identify some suitable proxy indicators of ocean growth and survival conditions that could be used as variables linking survival rates and growth to ocean conditions. Among other things, such variables could theoretically allow identification and separation of freshwater effects on survival of CWT groups as compared to ocean effects. Although it seems *a priori* reasonable to suppose that survival of CWT groups from release to age 2 is primarily a function of ocean conditions, especially for October releases of yearlings, there is also a suggestion (IGH flows vs survival rates of June fingerling releases) that high (upper) Klamath flows may have a substantial favorable impact on survival. This apparent effect may either be through reduction in downstream migrant mortality or through some unknown favorable impacts of the Klamath River plume on nearshore oceanographic conditions (increased nutrients encourage phytoplankton and zooplankton growth; increased turbidity reduces predation success; and so on). Ideally, two ocean variables would be useful: one to describe ocean conditions that may primarily affect survival, presumably shortly following ocean entry of smolts, and one to describe ocean conditions that may primarily reflect growth. We hypothesize that survival to age two is primarily affected by ocean conditions shortly after ocean entry, whereas size at age 2 primarily reflects ocean conditions following the critical survival period following ocean entry. For the IGH, TRH and CRH CWT release groups considered in this report, correlations between age 2 mean lengths at hatchery return and corresponding estimated survival rates from release to age 2 were in almost all cases quite weak (ranged from 0.16 - 0.64 for fingerling and yearling releases of IGH and TRH fall Chinook).

It is also important and perhaps critical to revive and/or further explore the "multi-cohort" analysis procedures outlined by Hankin and Mohr (1993) and further developed by Mohr (unpublished). We recommend revisiting/reconsidering the methods developed by Mohr because we are concerned that our various findings concerning estimated survival rates and maturation probabilities and their covariances among stocks may to some degree result from the fact that the single cohort analysis methods relied upon for this report require that one invoke an assumption that either survival rates or maturation probabilities are known. In this report, we assumed that ocean survival rates were known and had the values 0.5 for age 2-3, and 0.8 for age 3-4 and age 4-5. Although this set of assumptions seems more appropriate than making the alternative assumption that age-specific maturation probabilities are fixed and known, it is at odds with the preliminary findings of Hankin and Mohr (1993) and Mohr (unpublished) and it is also at odds with common sense. For example, Hankin and Mohr found that estimated ocean survival rates for IGH and TRH CWT groups varies considerably over the years they studied, with adult fish affected by the strong 1982-83 El Nino event having extremely survival rates (0.1-0.2 as compared to the assumed 0.8). Measurements of lengths at age for CWT release groups affected by the strong 1982-83 El Nino event showed consistently smaller lengths at age, a clear reflection of poor conditions for growth as a result of this event. This kind of very serious departure of apparent reality with assumed survival rates and its consequences for size at age could introduce very substantial (but generally unknown) bias in some years. It might also cause multiple stocks to appear to share strong interannual covariance in estimated maturation probabilities. For example, if cohort analyses assumed usual survival patterns, whereas adult survival between age 3 and 4 was unusually low, then estimated age 3 maturation probabilities might have a very serious positive bias due to serious underestimation of the number of fish that did not mature at age three, but which died at an unusually high rate due to during unusually poor ocean survival conditions between age 3 maturation and the following fall. Overall, these kinds of considerations make us believe that one should be extremely circumspect in interpretation of the degree of covariation of estimated parameters between stocks.

Nevertheless, the degree of observed covariation in estimated survival rates, length at age, and estimated maturation probabilities that was noted in this report was in a great many cases quite striking, and in almost all cases observed covariation was consistent with reasonable biological mechanisms. For estimated survival rates from release to age 2, covariation was strongest for the most closely related stocks released from the same hatchery at the same time (i.e., spring and fall Chinook released from TRH as fingerlings or as yearlings); was of intermediate strength for stocks released at approximately the same time at nearby hatcheries (e.g., IGH and TRH releases of fall Chinook as yearlings); was less strong though still highly significant for much less closely related stocks released at the same approximate time at hatcheries distant from one another (e.g., CRH and TRH spring Chinook salmon released in October); and was lowest and often not significant for stocks released at very different times (e.g., IGH fingerlings vs yearlings). These patterns are consistent with (a) survival rates of hatchery fish being largely determined by ocean conditions rather than conditions during freshwater migration; but (b) differences in freshwater downstream migration conditions must also affect post-release survival as covariance declines as less downstream migration history is shared; and (c) conditions for survival at ocean entry probably vary considerably within a given year because survival rates between fingerlings and yearlings released from the same stock type and hatchery are not necessarily strongly correlated. The final conjecture, (c), is least well supported because differences in survival rates for fish released in June as compared to October could alternatively reflect strong differences in conditions for downstream migration survival in those two months with ocean survival conditions being fairly stable.

One of the principle objectives of our CWT analyses was to determine whether or not survival rates of CWT groups are likely good indicators of ocean conditions for survival and whether recent survival rates for IGH releases of fall Chinook have decreased relative to TRH releases of fall Chinook, possibly due to recent changes in flow management in the upper Klamath (below IGH). As noted above, it appears that variation in survival rates of CWT release groups is primarily a function of variability in ocean conditions for survival, but it seems also clear that freshwater downstream migration history has a modest impact on survival to age 2. In the absence of an ”ocean environment variable” that might be suitable for analysis (e.g., the new ”Wells Production Index”), it is impossible to be much more definitive on this topic. However, we note that the very substantial short-term (between year) variation in estimated survival rates must be a reflection of local, nearshore conditions that affect survival of Chinook salmon smolts entering the ocean from the Klamath and Rogue rivers. Year-to-year variation is striking and appears of greater significance to these stocks that the kind of longer-term “favorable” or “unfavorable” conditions for survival that are implied by large-scale regime shifts in ocean climate (see, e.g., Mantua et al. 1997). Also, we note that our comparisons of estimated survival rates of fall Chinook salmon released from IGH and TRH did not indicate that there has been a recent decline in relative survival rates of IGH as compared to TRH releases. Although average survival rates of IGH releases are typically less that those of TRH releases, several exceptions to this generalization were evident in the past decade.

Although the confounding of ocean natural mortality rates with age-specific maturation rates may to some degree be circumvented by use of multi-cohort methods as compared to single cohort analysis methods, we remain concerned that there is no good fix to the problems posed by non-landed mortalities in ocean fisheries. Although errors in calculation of non-landed mortalities may be unlikely to affect the kinds of broad conclusions or trends noted in this report, they can have important impacts on allocation negotiations between ocean and freshwater fishers. In this report, we have proposed an alternative procedure for imputation of age 3 non-landed mortalities that accounts for the substantial interannual variation in size at age. We believe that this approach, or some more appropriate modification of our approach that addresses this same issue, is superior to the current imputation methods that assume a fixed schedule of monthly lengths. As our numerical examples illustrated, these alternative procedures would generate much larger estimates of non-landed mortalities in years when size at age 3 is unusually small, and much smaller estimates in years when size at age 3 is unusually large. These consequences seem quite reasonable to us, but we recognize that the example behavior of our proposed alternative (see Table 4.1) suggests that our proposed methods are off target. Among other things, the adjusted lengths seem ”too large” (exceed observed mean lengths at hatchery for age 3 mature fish for CWT code 065906) and they seem ”too small” in May for CWT code 065908 (and generate an implausibly large non-catch mortality total in May for that code). We have no doubt that our suggested approach can be substantially improved! Nevertheless, we reiterate our concern that length adjustments should be made at age 3 according to the relative size of age 3 fish at maturity.

We also express concern that failure to adequately address non-landed mortalities at age 2 must lead to negative bias in estimates of ocean fishery impacts, negative bias in estimates of survival to age two, and positive bias in estimates of age two maturation probabilities. We recognize that our recommendations for imputation of non-landed mortalities at age 2 inject yet another assumed parameter (age 2 contact rate compared to fully vulnerable fish), but we believe that it is highly inappropriate to ignore age 2 non-landed mortalities or to assume that they are non-existent because there are no landed CWT recoveries at age 2. If all age 2 fish were below legal minimum size limits, as is typically the case, then there would be no reported age 2 landings. That certainly does not imply that no age 2 fish were contacted or that no age 2 fish suffered non-landed mortalities. We believe that on-board observations on recreational and commercial vessels are needed to better assess the probably magnitude of non-landed mortalities at age 2.

Finally, effective long-term implementation of constant fractional marking (CFM) programs at IGH and TRH will in part depend on the mix of fingerlings and yearlings that are released from these facilities. To the degree that releases can be shifted away from fingerlings and toward yearlings, effective implementation of a CFM program would become more feasible. Letting S_{rel} denote the average survival rate to age 2 of yearlings as compared to fingerlings, the device of increasing yearling releases by the factor X/S_{rel}, where X denotes a corresponding reduction in fingerling releases, would achieve an expected total catch and escapement of adults that is very close to the original policy (especially in terms of biomass landed in fisheries). Any potential shift toward yearlings must also be balanced against the fishery management need for sufficient numbers of fingerlings to be released to allow for estimation of life history and fishery parameters important for fishery management analysis. Based on the simulations of the performance of the cohort analysis estimators of these parameters, it appears to adequate release group sizes are somewhere between 200,000 and 400,000 fish. If such release group sizes were achieved by pooling across all CWT groups of the same release type from a given brood year, then a 25% CFM rate would imply that minimum total fingerling fall Chinook salmon releases should range from about 800,000-1,600,000, with 1,000,000 being a reasonable target value (i.e., 250,000 fish receiving CWT). Falling below this range would likely result in a substantial increase in errors of estimation associated with important management parameters that are currently estimated from CWT recovery data.

Chapter 6

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