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same trends in abundance. Although several more estimates made using both approaches will be required before we can reasonably describe their statistical relationship (e.g., through regression), these initial signs of accuracy are promising.

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Notes

Ken Newman (Mathematical Statistician, US Fish and Wildlife Service), e-mail, 27-Jan-2011

Length-at-Date Criteria to Classify Juvenile Chinook Salmon in the California Central Valley: Development and Implementation History

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Introduction

California is unique in having four different spawning runs of Chinook salmon in the Sacramento River, resulting in a mixed population of juveniles in the river and downstream habitat. Identifying the offspring of these four runs (fall, late-fall, winter and spring) is particularly challenging as the runs are distinguished by the timing of adult spawning migrations, rather than juvenile behavior or appearance. The current solution is to classify the run origin of juveniles in this mixed population using length-at-date size criteria. Length-at-date criteria are the expected fork-length ranges of each run at each calendar date. Length-at-date criteria are organized into tables such that the fork-length of any Chinook salmon juvenile encountered in the Central Valley can be compared to the expected length ranges for the encounter date, and classified to run accordingly. Length-at-date classification is the accepted approach for designating run origin of juvenile Chinook salmon in the Sacramento and San Joaquin rivers and the Delta, and is central to loss and take estimates of threatened and endangered Chinook salmon runs at state and federal water pumping facilities. Since take estimations can affect the operations of the California State Water Project (SWP) and the federal Central Valley Project (CVP), the accuracy or inaccuracy of run classifications has enormous implications both for the persistence of Chinook salmon runs and for water use in California. Considering the importance of salmon and water to the California economy, it is surprising that the development of length-at-date size criteria is so poorly documented that few people are aware of the theory, assumptions and supporting data upon which the criteria are based. Following is an account of the development and implementation history of length-at-date size criteria for juvenile Chinook salmon in the California Central Valley. As the details of this account were pieced together from memoranda, meeting minutes and unpublished draft reports, those who participated in this history may find inaccuracies with their own recollections. Corrections may be directed to the author for inclusion in future revisions of this document.

Regulatory Basis for Run Classification

In February1992, as a result of the listing of Sacramento River winter-run Chinook salmon as threatened under the federal Endangered Species Act, National Marine Fisheries Service (NMFS) issued a biological opinion including an incidental take permit for operations of the SWP and the CVP in the Sacramento-San Joaquin Delta{NMFS, 1992 #37}. The juvenile winter-run take limit was set at 1% of each year's estimated population. Since juvenile Chinook salmon in the Delta was a mixed population of progeny from the four Central Valley runs, a method for designating run-origin for juvenile salmonids was needed to tally the take of winter-run versus non-winter run Chinook salmon at the SWP/CVP water pumping facilities.

Initial Efforts to Develop Length-at-Date Criteria

A length-at-date approach for identifying winter-run Chinook salmon juveniles was originally proposed by Stevens (1989) to estimate the timing of winter-run outmigration through the Delta. Stevens, a fisheries management supervisor at the Department of Fish and Game (DFG), observed that adult Chinook salmon within a given run tend to spawn, and their progeny emerge, at the same general time of each year, while the spawning and emergence times of different runs tend to be segregated. From this he reasoned that the range of juvenile fork-length for any given calendar date could be estimated by determining the earliest and latest emergence times of each run and then extrapolating size at emergence into the future by applying knowledge of juvenile growth rates. Stevens enlisted Frank Fisher (DFG) to plot points on a two-dimensional graph with the earliest and latest emergence time of each run as the x-coordinate, and the average size of Chinook salmon at emergence as the y-coordinate. Each point served as an intercept for a separate log-linear regression line, with the slope of all lines equal to a Chinook salmon growth-rate estimate used by hatchery managers at the time (Figure 1).

Fisher (1992) recognized that the hatchery-based growth rate, which assumed a doubling of fish weight every month, over-estimated growth of naturally occurring salmon, and was therefore inadequate for estimating wild Chinook salmon length-at-date. However, Fisher also recognized that growth rate estimation in wild Chinook salmon populations was complicated by variability in emergence times, sampling inefficiencies, immigration and emigration. As a compromise, Fisher opted to replace the growth rate from Stevens (1989) with a growth rate estimated from juvenile fall-run Chinook salmon that had been spawned and reared in artificial spawning channels attached to the Tehama-Colusa Canal near Red Bluff Diversion Dam. Fisher described the growth rate of these juveniles as "natural" because the juveniles were produced by natural spawning activity of ripe adults placed in the spawning channel and the embryos were incubated in gravel. However, "natural" is a somewhat inaccurate descriptor since juveniles in the Tehama-Colusa Canal were reared on hatchery food, and juvenile densities were artificially maintained in the spawning channels.

To estimate growth rate, Fisher (1992) calculated average condition factor (CF) from weight and count data of Chinook salmon juveniles, compiled at weekly intervals from 1972-1981, where

$$CF=0.000730-0.00005*\ln(count/weight) \quad (1)$$

The parameters of this equation were derived from eleven measurements of average CF that had been taken at different stages of juvenile growth and then regressed against fish count per bulk fish weight. The report does not document the origin of these eleven data points. The standard equation for condition factor,

$$CF = 10^5 * mass/(fork\text{-}length)^3 \quad (2)$$

was manipulated to convert average CF for each week to average fork-length,

$$fork\text{-}length = (10^5 * mass/CF)^{1/3} \quad (3)$$

Note that average mass per fish was estimated by dividing the weight of a fish sample by the count of fish in the sample (weight/count), while average CF was estimated from the reciprocal of this quotient (count/weight) using equation 1. Average fork-length data derived from equation 3 were pooled to estimate the parameters for a log-linear, fork-length growth equation. Since the above equation yielded an emergence size at day zero (31 mm) that was smaller than the average observed Chinook salmon emergence size (34 mm), Fisher adjusted the intercept of the equation to force a 34 mm fork-length at emergence (day zero) while maintaining the same growth rate, resulting in,

$$\ln(\text{fork-length}) = 3.516464+0.006574 * \text{days} \quad (4)$$

where days is the time from peak emergence of fry in the Tehama-Colusa Canal spawning channel, assessed separately for each year.

Substituting early and late emergence times of each Chinook salmon run for days in equation 4, Fisher used this fork-length growth-rate equation (based on fall-run Chinook salmon) to construct a table of expected fork-length ranges for juveniles of all four runs in the Central Valley (Figure 2). Early and late emergence times for each run were estimated as the number of days required for eggs to accumulate 1500 temperature units following the date of early and late spawning activity where average early and late spawning activity for each run was based on Hallock (Hallock 1973) and other reports of spawn timing. A temperature unit is accumulated for each degree Fahrenheit exposure above freezing in each 24-hour period. Fisher estimated temperature units for all runs in the Sacramento River drainage using average monthly water temperatures at Bend Bridge near Red Bluff. Although growth rate in equation 4 was estimated from juvenile growth up to 90 mm FL, Fisher (1992) used the equation to extrapolate fish growth up to 270 mm FL. Equation 4 and the length-at-date tables based on it have been variously referred to in subsequent reports and inter-departmental correspondence as Frank's Model, the Fisher Model, the DFG Model and the original DFG Model. In this document it will hereafter be called the Fisher Model.

When Fisher issued a draft report describing the Fisher Model in June of 1992, the length-at-date table based on his model had already been in use for several months to estimate winter-run take from salvage data at the SWP and CVP facilities. However, the original Fisher Model length-at-date table only provided size criteria at bimonthly intervals (Figure 2). These size criteria were not averages for the entire first and last half of each month, but rather discrete estimates of size ranges for the four Chinook salmon runs at the beginning and midpoint of each month. The classification of Chinook salmon encountered between these dates could be ambiguous. For instance, a 47 mm Chinook salmon captured on December 7 (between dates with size criteria) would be greater than the 45 mm maximum fork-length for spring-run Chinook salmon based on December 1 criteria, but smaller than the 49 mm minimum fork-length for winter-run Chinook salmon by based on December 16 criteria. Ambiguous fork-lengths such as this created overlap categories between run classification boundaries (Figure 3). Chinook salmon with fork-lengths falling within these overlap categories were double classified (e.g. spring,-winter-run).

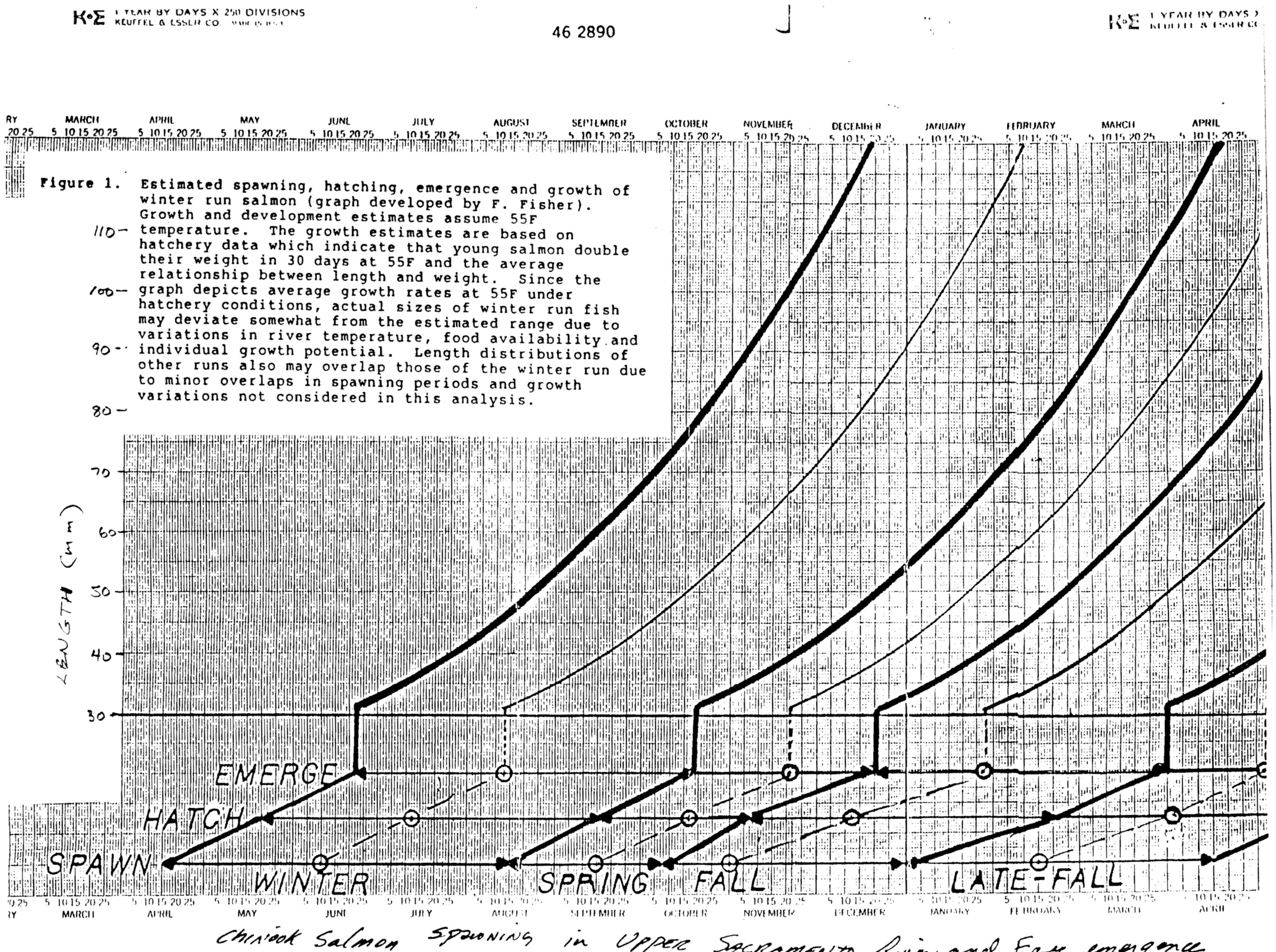

Figure 1 Fisher's original length-at-date chart for Chinook salmon in the upper Sacramento River from Stevens (1989).

DATA FROM TCFFOUT.WK1 REGRESSION
GROWTH CURVES FOR INDIVIDUAL RACES
(MM FL.)

SPAWNING	FALL RUN			L.FALL RUN			WINTER RUN			SPRING RUN		
	EARLY	PEAK	LATE	EARLY	PEAK	LATE	EARLY	PEAK	LATE	EARLY	PEAK	LATE
TIME	OCT1		DEC31	JAN1		APR15	APR16		AUG15	AUG16		SEP30
EMERGE	DEC10		APR2	APR3		JUN27	JUN28		OCT18	OCT19		DEC9
DEC	34			166	122	89	89	65	45	45	41	34
mid month	37			181	136	99	99	73	49	49	45	37
JAN	41			200	150	110	110	80	54	54	49	41
	45			219	166	122	122	89	59	59	54	45
FEB	49	34		244	181	136	136	99	65	65	59	49
	54	37		270	200	150	150	110	73	73	65	54
MAR	59	41			219	166	166	122	80	80	73	59
	65	45			244	181	181	136	89	89	80	65
APR	73	49	34	34	270	200	200	150	99	99	89	73
	80	54	37	37		219	219	166	110	110	99	80
MAY	89	59	41	41		244	244	181	122	122	110	89
	99	65	45	45	34	270	270	200	136	136	122	99
JUN	110	73	49	49	37			219	150	150	136	110
	122	80	54	54	41			244	166	166	150	122
JUL	136	89	59	59	45	34	34	270	181	181	166	136
	150	99	65	65	49	37	37		200	200	181	150
AUG	166	110	73	73	54	41	41		219	219	200	166
	181	122	80	80	59	45	45	34	244	244	219	181
SEP	200	136	89	89	65	49	49	37	270	270	244	200
	219	150	99	99	73	54	54	41			270	219
OCT	244	166	110	110	80	59	59	45				244
	270	181	122	122	89	65	65	49	34	34		270
NOV		200	136	136	99	73	73	54	37	37	34	
		219	150	150	110	80	80	59	41	41	37	
DEC		244	166	166	122	89	89	65	45	45	41	34
		270	181	181	136	99	99	73	49	49	45	37
JAN			200	200	150	110	110	80	54	54	49	41
			219	219	166	122	122	89	59	59	54	45
FEB			244	244	181	136	136	99	65	65	59	49
			270	270	200	150	150	110	73	73	65	54
MAR					219	166	166	122	80	80	73	59
					244	181	181	136	89	89	80	65
APR					270	200	200	150	99	99	89	73
						219	219	166	110	110	99	80
MAY						244	244	181	122	122	110	89
						270	270	200	136	136	122	99
JUN								219	150	150	136	110
								244	166	166	150	122
JUL								270	181	181	166	136
									200	200	181	150
AUG									219	219	200	166
									244	244	219	181
SEP									270	270	244	200
												219
OCT												244
												270

VERIFIED AND REVISED 2/26/92
SLOPE REMAINS THE SAME. LENGTH INTERVAL SHIFTED TO CORRESPOND TO OBSERVED LENGTHS AT HATCHING.
SIZE RANGE UPON HATCHING 28–35 MM.

Figure 2 Original bimonthly length-at-date table from Fisher (1992). For each date, fork length thresholds are read in a row from right to left. For each run, the fork length on the right is the minimum size expected for that run, representing late-spawned, late-emerged Chinook salmon; the fork length on the left represents maximum size or earliest-spawned Chinook salmon.

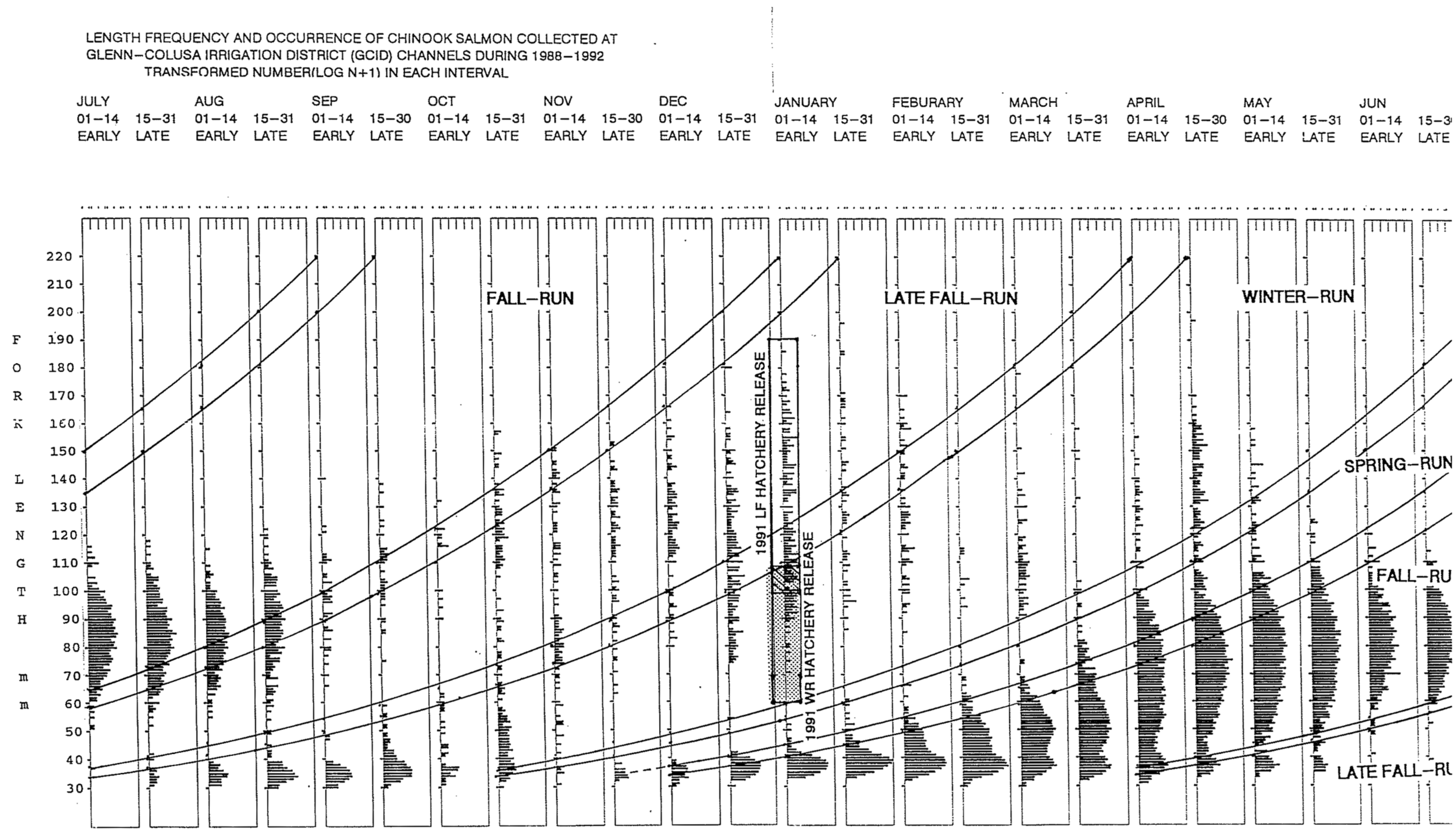

Figure 3 Length at Date boundaries based on Fisher Model bimonthly interval table showing overlap areas between runs. Figure from Fisher (1992).

Additional Refinements

By early 1992, Department of Water Resources (DWR) was using Fisher's original bimonthly table to estimate winter-run take at the Delta pumping facility. At the same time, DFG was estimating winter-run take at the Delta pumping facility using a similar table produced by the Fisher Model, but with monthly rather than bimonthly intervals. The larger time intervals in the monthly table resulted in larger overlap zones and caused discrepancies between DWR and DFG take estimates. To alleviate these discrepancies and forestall the possibility of disagreements about whether or not to include double-classified Chinook salmon in take estimates, Sheila Greene (DWR) created a daily-interval table with no overlap categories (Greene 1992). To create the table, Greene fitted a log-linear regression equation to the bimonthly size boundaries in Fisher's bimonthly table,

$$\ln(FL,mm) = 3.49470+0.0065678*days \qquad (5)$$

and then used this equation to interpolate daily size thresholds between bimonthly points. Comparison with Fisher's (1992) original fork-length growth equation (equation 4) shows equation 5 is effectively a reproduction of the Fisher Model equation with small differences in parameter values. Since 1992, Greene's daily-interval version of the Fisher Model length-at-date table has been used to designate Chinook salmon juvenile run-origin in the Sacramento River, although the name has been changed from the Fisher Model to the "River Model." Greene's daily-interval table was also used to designate run-origin in the Delta and to estimate winter-run Chinook salmon take at SWP and CVP facilities until it was replaced by the "Delta Model" in April, 1997.

The Delta Model, along with a Modified Fisher Model (aka modified DFG Model), a separate USFWS model developed from the same data as the Fisher Model, and the Seine Model, were all developed in 1994 by a subcommittee of the interagency Winter-run Monitoring and Loss Group. The interagency subcommittee, dubbed the Size Criteria Group, was established in response to a memorandum sent from the director of DWR to the Governor's Water Policy Council (Gibbons 1994), a council comprised of directors of state departments and secretaries of state agencies with a direct interest in state water policy. The memorandum questioned both the validity of Fisher Model size criteria used to designate Chinook salmon juvenile run-of-origin and the true identity of Chinook salmon salvaged at the SWP fish protection facility that were designated winter-run using the Fisher Model size criteria. To support this criticism, the memorandum stated that coded-wire tagged fall-run Chinook, originating from a hatchery, had been salvaged at the SWP fish facility and misclassified as winter-run Chinook by Fisher Model size criteria. The Size Criteria Group was tasked with modifying or replacing the Fisher Model to produce a new model for predicting Chinook salmon run-origin using length-at-date data in the Delta. The new model was expected to generate size criteria that better differentiated winter-run Chinook salmon juveniles in the Delta from juveniles of other runs, primarily the fall-run. More specifically, the fork-lengths separating winter-run from other runs at any given date were expected to be higher relative to the Fisher Model, so that fewer Chinook salmon at the upper end of the fall-run size distribution would be classified as winter-run and included in winter-run take. This objective stemmed from a suspicion among Size Criteria Group scientists that winter-run growth rate in the Sacramento River is greater than the fall-run growth rate, based on speculation that higher water temperatures during winter-run residence in the Sacramento River cause faster growth rates (Holsinger 1995). Size Criteria Group members also believed juvenile growth rates of all Chinook salmon runs in the Delta are greater than in the Sacramento River (Holsinger 1995). The primary evidence of faster Delta growth rates was a study by Size Criteria Group member Martin Kjelson (1982), which compared growth rates between the upper Sacramento River and Delta, using mark-and-recapture of fall-run hatchery fry.

The Size Criteria Group developed the four alternatives to the Fisher Model over the next several months. The changes in the winter-run length-at-date boundaries projected by the alternative models are projected in Figure 4. Fisher, also a member of the Size Criteria Group, presented a modified version of his original model that simply raised the intercept of the growth equation (equation 4) from average observed emergence size (34 mm) to maximum observed emergence size (41 mm), while retaining the same growth rate obtained from the Tehama-Colusa Canal spawning channel. The modified Fisher Model met the objective of raising the winter-run lower size threshold, but also raised all the other size thresholds, which was not supported by length-frequency data from the Delta (Holsinger 1995). The USFWS conducted an independent analysis of Tehama-Colusa Canal fish data to determine new growth rates for estimating winter-run size criteria (USFWS 1994). This analysis was identical to Fisher's (1992) original analysis, except upper and lower 95% confidence limits were calculated for the count-per-bulk-weight to condition-factor conversion equation. These confidence limits were propagated through the remaining Fisher Model conversions and calculations to provide 95% confidence limits for growth rate, which were in turn used to determine winter-run upper and lower size criteria.

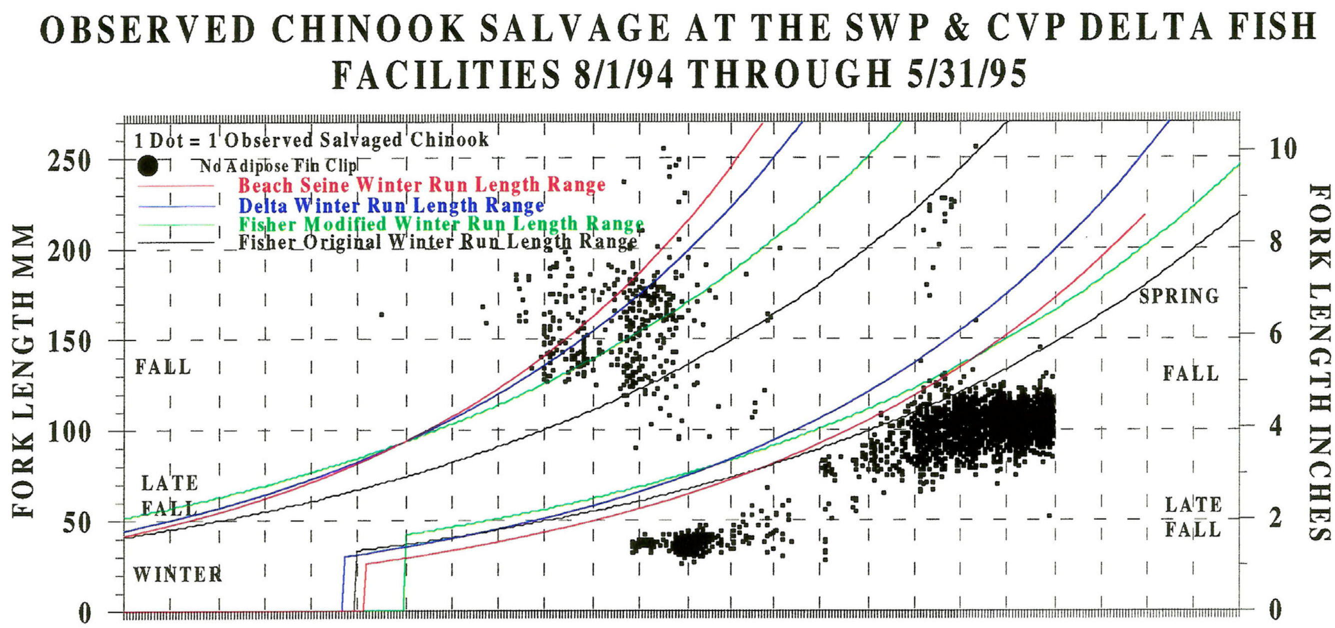

Figure 4 Winter-run Chinook salmon length-at-date boundaries projected by the Greene daily-interval version of the original Fisher Model, and three alternative models developed by the Size Criteria Group in 1994. Delta Model size criteria are from Mark Pierce's original Delta Model length-at-date table. Figure from Greene (1995).

A third alternative, offered by Size Criteria Group member Jay Bigelow (USFWS), was the Seine Model, so named because it was developed from analysis of Chinook salmon length-frequency histograms from beach seine sampling at 14 sites in the upper Sacramento River (RM 164 to 300) over the 14 year period from 1980 to 1994 (Bigelow 1994). The stated goal of Bigelow's analysis was to develop size criteria for winter-run Chinook salmon in the Delta from length-frequency data. Daily seine data was separated into distinct clusters with an objective algorithm. Clusters were pooled across years, but separated by site and day of the year, and then assigned to either winter or fall-run through an iterative regression process. In the iterative process, each length-frequency cluster was initially assigned to a run based on Fisher Model size criteria. For each run at each site, separate regressions lines were generated from cluster maximum and minimum fork-lengths (cluster tops and bottoms) intercepts taken from the Fisher Model (fork-length = 34 mm at earliest and latest emergence dates), except that emergence date ranges for fall and spring-runs were lumped together for fall-run. The outer 95% confidence intervals of these regression lines were used to reassign clusters to run. The regression process was repeated until consecutive regressions yielded the same parameters. Then for each run, clusters (based on final designation) were pooled across sites and a final regression was conducted for cluster tops and bottoms. The outer 95% confidence intervals of the final regression lines were used to establish length-at-date criteria for each run. Since data limitations only allowed estimation of winter-run and fall-run boundaries, fork-lengths between the upper winter-run and lower fall-run boundaries were assigned to late fall-run.

To determine if length-at-date patterns from the upper Sacramento River differ from patterns in the lower Sacramento River and Delta, Bigelow (1994) attempted similar analyses for beach seine data collected from these regions. Although length-frequency clusters were apparent for most lower Sacramento River and Delta locations, there was not sufficient sampling during the winter months to develop regressions from the length-frequency clusters. However, Bigelow found length-frequency clusters from lower Sacramento River locations fit reasonably well within upper Sacramento River size criteria, while fork-length clusters from most Delta locations suggested fall-run growth rates were higher in the Delta.

The Delta Model, created by Mark Pierce (USFWS) was essentially Greene's daily-interval length-at-date table, based on the original Fisher Model, with modified upper and lower boundaries for winter-run Chinook salmon. The modified winter-run size criteria were determined from length-frequency histograms compiled for non-adipose clipped Chinook salmon from sampling efforts throughout the Delta from 1973 to 1994. This pooled data set was comprised of 140,087 records including USFWS beach seine data (1976-1993), data supplied by Ray Shafter of DFG (10,000 records collected year round, 1973-1974), USFWS trawling data from Sacramento and Chipps Island (1991-1993) and Montezuma Slough (1992-1993), fyke net data from Sacramento (1992-1993), rotary screw trap data from the Sacramento Cross Channel (1993), push net data (1993) and salvage data from the CVP and SWP south Delta fish facilities (1980-1994). Data was pooled across years but separated at bimonthly intervals (e.g. early December, late December). For each bimonthly period a lower boundary for winter-run fork-length was selected by hand from the apparent break between fall-run and winter-run clusters in the length-frequency histograms. Although there were a large number of records in the dataset, the analysis of length-frequency histograms produced only thirteen breakpoints. The natural log of these thirteen break points were regressed against day of the year to obtain an equation representing the lower fork-length boundary for winter-run Chinook salmon in the Delta.

$$\ln(FL) = 3.401 + 0.008157*days \qquad (6)$$

Day = 0 was set at October 12th. Upper boundary break points for winter-run were not clear in the length-frequency histograms. Therefore the upper length-at-date boundary was estimated as a line with the same slope as the lower boundary, but with an intercept point set at the largest size (94 mm) of winter-run Chinook salmon entering the Delta, as predicted by the Seine Model, with November 1 as the assumed earliest entry date of winter-run juveniles into the Delta. The regression equations were then used to replace the size criteria for winter-run Chinook salmon in Greene's daily-interval length-at-date table, leaving the Fisher Model size criteria for the other runs unchanged. Sizes below 94 mm for the upper boundary were extrapolated backward to 34 mm with a slightly reduced regression slope of 0.0081, allowing day = 0 to fall on July 1. For models based on Sacramento River growth rates, day = 0 corresponds to assumed earliest and latest emergence dates for a given run. This is not the case for the Delta Model. Instead, the date when day = 0 for the Delta Model boundary equations corresponds to the date when back-extrapolated fork-length equals the average observed emergence size for fall-run Chinook salmon taken from Fisher (1992). Since Chinook salmon fork-lengths are expected to correspond to Delta Model growth rate and size categories only upon entering the Delta, the date in the Delta Model length-at-date table where day = 0 is somewhat meaningless in the context of Chinook salmon life stage.

The concluding report of the Size Criteria Group recommended the Seine Model be adopted in the Sacramento River and either the Seine Model or Delta Model be adopted in the Delta for designating juvenile Chinook salmon run-origin. The group reasoned these models were more protective for identifying winter-run Chinook salmon because of a broader winter-run size range than the other models (Holsinger 1995). The group found the original and modified Fisher models and the USFWS model were unreliable for estimating run-origin of juvenile Chinook salmon in the Delta because, like the original Fisher Model, they were based on the questionable assumptions that, 1) fish in the Tehama-Colusa artificial spawning channel grow at the same rate as fish in the Sacramento River, and 2) juveniles of all races grow at the same rate as fall-run, even though juveniles of each run, at a given developmental stage, experience different environmental conditions (e.g. temperature, food availability) due to different emergence times and migration patterns.

The group considered the Seine Model more "biologically valid" than the Delta Model for use in the Delta because, 1) the Seine Model separately estimated size criteria for winter-run and fall-run, while the upper boundary of winter-run size criteria in the Delta Model was derived from a growth rate based on the upper boundary of fall-run size criteria, 2) the length-frequency data used to develop the Seine Model contained a large proportion of winter-run Chinook salmon, while the Delta Model dataset contained a small proportion of winter-run Chinook salmon relative to fall-run Chinook salmon, 3) Seine Model size criteria were developed from objective assessment of length-frequency data and encompassed 95% confidence intervals, while the designation of size thresholds for the Delta Model were somewhat arbitrary, with difficult-to-distinguish breaks between length-frequency clusters drawn in by hand, and 4) the Delta Model suggested slower maximum growth of winter-run in the Delta than the Seine Model suggested in the upper Sacramento River, which ran contrary to the group's expectation that growth would be more rapid in the productive Delta. The report suggests that the Delta Model may become more robust and a better choice in the future as more data is collected in the Delta.

Following completion of the subcommittee report, NMFS did not revise the CVP/SWP biological opinion to implement any of the alternative models for salvage and loss estimates. NMFS was concerned that the models, which were primarily focused on excluding the April/May pulse of fall-run juveniles from winter-run size criteria, did not adequately address size criteria separating the other Chinook salmon runs, particularly earlier in the juvenile migratory season (December – March). However, on March 25, 1997, DWR notified NMFS that the Delta export facilities exceeded 1% of that year's estimated population (Hogarth 1997). When the 2% take limit was exceeded the following day, on March 26, 1997, NMFS initiated interagency discussions to review take estimation procedures. On April 7, 1997, NMFS issued a letter to DWR and the U.S. Bureau of Reclamation implementing replacement of the Fisher Model with the Delta Model for estimation of winter-run take at the Delta export facilities, to be applied retroactively to estimate take for the entire 1996-1997 juvenile out-migration season (Hogarth 1997). The revised take estimate using Delta Model size criteria fell well below the 2% of population limit.

To support the decision to replace the Fisher Model with the Delta Model, the NMFS letter outlined the following conclusions of its review of take estimation procedures:

- The Fisher Model represents Chinook salmon growth rates in the upper Sacramento River and should not be expected to adequately distinguish winter-run Chinook salmon from the other runs in the Delta where growth rates may be higher.

- Chinook salmon in the Fisher Model winter-run size criteria were collected in the San Joaquin River where no winter-run occurs.

- The pulse of juvenile Chinook salmon that was responsible for the exceedance of take had begun in late March when historical records suggest most winter-run should have already completed seaward migration.

- Most Chinook salmon causing exceedance of take by Fisher Model criteria were near the lower size threshold for winter-run and appeared to be part of a large population that fell mostly within fall-run size criteria.

- Preliminary results for newly developed diagnostic genotypes indicated many fall-run at the large end of the population size distribution were wrongly designated winter-run by Fisher Model size criteria.

There was no indication in the letter why the Delta Model was chosen over the Seine Model.

Although initially adopted only for the 1996-1997 season, following a more thorough review of salmon emigration data and genetic analyses provided by researchers at Bodega Marine Lab, NMFS authorized continued use of the Delta Model for take estimation at Delta water export facilities. The length-at-date table in current use at the CVP and SWP Delta export facilities is essentially the same table adopted for use in April 1997, with minor differences in winter-run upper-boundary size criteria corresponding to a slight reduction in the upper boundary regression slopes. Slope reductions were from 0.0081 to 0.008 for size criteria before November 1, and from 0.00816 to 0.00806 for size criteria after November 1. The maximum change in winter-run size criteria caused by this slope change was 2 mm, occurring at the earliest appearance of winter-run in the Delta Model length-at-date table. Most likely, these minor changes were caused by rounding errors during reproduction of the length-at-date table over the years.

Discussion

When reviewing the history of size criteria development and implementation it is important to remember that resource managers were faced with a rapidly declining population of winter-run Chinook salmon and required an immediate method for distinguishing juvenile Chinook run origin within a mixed population. The method needed to be fast and simple enough to allow near real-time assessment of winter-run take at state and federal water export facilities, yet provide a level of accuracy that would minimize misclassification of run-origin. The economic, political and ecological implications of inaccurate classification were (and still are) enormous. Winter-run misclassified as non-winter-run could jeopardize survival of the run, while misclassification in the other direction could lead to erroneous curtailment of water exports. Resource managers adopted the length-at-date classification approach and associated size criteria because it was the best available science at the time.

Over the years, with continued use, Fisher Model and Delta Model size criteria have become established standards, even while knowledge of the origins of the criteria have slipped into obscurity. As a result, few (if any) practitioners currently using the length-at-date approach are aware of the tenuous assumptions and disjointed or limited datasets used to develop the size criteria. Fortunately, new classification approaches are under development or consideration. These new approaches range from rapid, real-time DNA analysis, to fine-scale evaluation of morphological characteristics, to analyses of multiple environmental variables to predict arrival of juvenile Chinook salmon pulses at pumping facilities. All of these approaches share a reliance on accurate DNA-typing of the individual fish used for model parameterization. Any one of these approaches has the potential to provide a more rigorous and dependable means for assessing the run origin of juvenile Chinook salmon encountered in the Sacramento River and the Delta.

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