



IMF Technical Memorandum #3

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Please Note: Since this Technical Memorandum was originally published, the version of the delta survival function has been changed based on additional analyses. Thus, this memo presents an older version of the delta survival function that is no longer used in the Winter Chinook IMF. For a description of the delta survival function currently used in the IMF, please refer to the IMF User's Guide (version 1.2).

Testing the Winter-run Chinook Model: Smolt Survival Through the Delta

Introduction

This is the third Technical Memorandum to explain how we applied historical data to test how well past trends in spawner abundance of winter-run Chinook could be predicted by the Integrated Modeling Framework (IMF). The first memorandum related to historical spawner abundance and egg survival, and the second related to historical harvest rates. This memorandum describes our derivation of estimates since 1968 for juvenile survival during migration through the Delta. This is an important life stage to model for two reasons: 1) Delta survival is highly variable, and 2) many factors affecting that survival are human caused. Average survival of juvenile winter-run Chinook passing through the Delta has not been directly estimated by sampling in any year, so we needed to develop a means of accounting for variation in this survival when attempting to



predict historical population trends. We will discuss the data and methods used, as well as their limitations.

What Factors Affect Survival Through the Delta?

There has been much analysis of factors influencing survival of juvenile fall-run Chinook passing through the Delta, but little on juvenile winter-run Chinook that pass in a different season and at a larger size. Accordingly, we derived our approach from studies with juvenile fall-run Chinook, and assumed they were applicable to winter-run chinook. We corroborated the reasonableness of that assumption by comparing our results against those of Brandes (2003), who used data from tests during late fall and winter with coded-wire-tagged (CWT) juvenile Chinook near the Delta Cross Channel (DCC; see map in Figure 1).

The most comprehensive analyses of data on factors affecting juvenile Chinook survival through the Delta have been those of Newman and Rice (1997) and Newman (2000). These works were later published as Newman and Rice (2002) and Newman (2003).

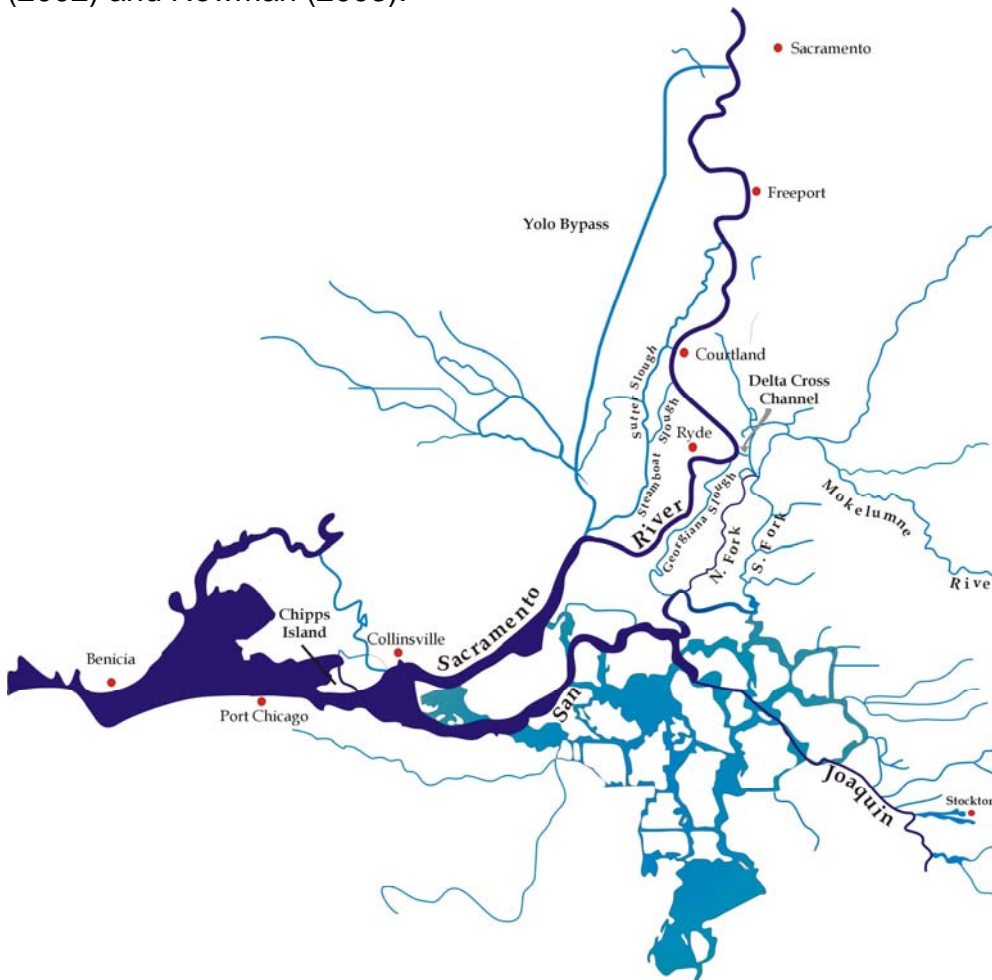


Figure 1. Map of the lower Sacramento River and Delta.



Newman and Rice (1997) analyzed survival estimates from CWT recoveries of fall Chinook released above and below the DCC each spring between 1979 and 1995. They found that temperature was the most influential environmental variable related to survival. Their work also indicated that flow, DCC gate position, and export-to-inflow ratios may also influence Delta migration survival, but those relationships were not statistically significant.

The work of Newman (2000) improved on the work of Newman and Rice (1997) in estimating Delta survival and further isolated factors correlated with survival. Newman and Rice (1997) conducted their analyses on trawl recoveries at Chipps Island of CWT-marked Chinook, and used catch/fish released as an index of survival. Thus, variation in trawl efficiency would have added error to the index. Newman (2000) advanced the analysis by directly estimating Delta survival from recoveries of paired CWT groups: groups released at the entry to the Delta were paired with groups released at the exit to the Delta. The paired analysis of Newman (2000) estimated survival through the Delta as a function of the difference in ocean recovery rates for fish released in the river near Sacramento compared to those released at Port Chicago or Benicia (Figure 1). Newman (2000) found that the majority of cases in which estimated survival was near 100%, flows exceeded 15,000 cfs and in all cases occurred only when release temperatures were less than about 65° Fahrenheit. In further analysis on the effects of covariates on survival Newman (2000) found:

“Flow effect can be seen to have the largest effect: as flow increases from 600 cfs to 15,000 cfs, survival increases from 0.37 to 0.67. The release temperature effect is sizeable as well, with 40% decrease in survival as temperature increase from 58 to 76 degrees Fahrenheit. At a moderate flow of 8,100 cfs, the export effects are also sizeable. As export/inflow increases from zero to 49% (within the historical range of export/inflow values when flow was around 8,100 cfs), survival rate declines 22%. The effect of the cross-channel gate being open is estimated to be roughly 18% decline in survival.”

Newman (2003) compared results of his paired analysis with that of the earlier unpaired analysis (Newman and Rice 1997). He found that the positive or negative effect of each of the variables was similar between the two analyses, but the significance of each relationship was consistently stronger for the paired analysis. Flow had the strongest association with survival in the paired model, whereas temperature had the strongest effect in the unpaired model. Temperature still had a significant negative effect on survival in the paired model, but the magnitude of the effect was less. The effect of the exports was greater in the paired model.

In his final analysis of paired CWT releases, Newman (2003) compared three statistical techniques for estimating environmental effects on survival, and concluded the hierarchical formulation was the most reliable. Thus, we used his hierarchical formulation in our modeling. Newman (2003) estimated coefficients for a number of factors that might affect smolt survival, but we used those factors pertinent to our analysis and that had statistically significant effects on survival.



Those factors for which we included coefficients estimated by Newman (2003) were: river inflow, river temperature, exports, DCC gate position, turbidity, and salinity (Table 1). Newman (2003) also found significant reductions in survival for fish released upstream at Sacramento rather than at Ryde, but we did not include this effect because the juvenile production (JPE) portion of our model already predicted survival to the point of Delta entry (JPE averages survival estimates from Battle Creek to various points representing Delta entry; Sacramento to Ryde). We also did not include the effect of size, because Newman (2003) showed that estimates of that coefficient changed substantially between model formulations.

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The equation we used to estimate survival through the Delta, based on coefficients estimated by Newman (2003) is as follows:

$$\text{Survival} = -1.02 + 0.56 \cdot \log_e(\text{Flow}) - 0.56 \cdot \text{River Temp.} - 0.21 \cdot \text{Exports} + 0.04 \cdot \text{Turbidity} + 0.23 \cdot \text{Salinity} - 0.60 \cdot \text{Gate Position}$$

Where:

Flow = Mean flow in cubic feet per second at Freeport.

River Temp. = Mean temperature in Fahrenheit at Freeport

Export flow = Combined export flow to the State and Federal pumps

Turbidity = Turbidity of river in formazine turbidity units near Courtland

Salinity = water salinity measured by conductivity, $\mu\text{mho/cm}$ at Collinsville

Gate Position = Average of daily positions of the Delta Cross channel gates where each day a value of 0 or 1 signaled both gates closed or open, respectively.

Newman (2003) standardized all variables except the DCC position indicator using the following equation:

$$\text{Standardized Value} = (\text{Observation} - \text{Mean}) / \text{Standard Deviation}$$

The mean and standard deviations for each variable were those reported by Newman (2003) from the observations in the dataset for paired CWT releases.



Table 1. Coefficients for environment variables used to estimate winter-run Chinook Delta survival. Relationship presented is the hierarchical formulation in Table 5 of Newman (2003). These coefficients estimate the logistic transform of survival. Coefficients of all variables except the gate indicator are for standardized variables.

Covariate	β	SE
Intercept	-1.02	0.10
\log_e (River Flow)	0.56	0.09
River Temperature °F	-0.56	0.07
Export Flow	-0.21	0.07
Turbidity	0.04	0.10
Salinity	0.23	0.07
Gate Position Indicator	-0.60	0.13

The equation we used includes salinity, which Newman (2003) reported was highly correlated to flow ($r = -0.79$). Although the two variables are negatively correlated, they both have a positive effect on survival (coefficients are positive). The combination of these effects results in a non-linear relationship between predicted survival and flow, because increasing flow reduces salinity, which decreases the benefit of flow to survival. We determined the relationship between salinity and flow by regressing salinity at Collinsville since 2000, and Sacramento River inflow at Freeport. The data set was limited to observations taken between December and March, because this is the primary time period when winter Chinook pass through the Delta. There was a strong negative exponential decline in salinity as flow increased ($p < 0.0001$, $r^2 = 0.65$) (Figure 2). This relationship is incorporated into IMF so that simulation of future scenarios including different flows will account for changes that flow causes in salinity. In the simulation of historic conditions, we did not link flow and salinity, but rather input the actual observed values of each.

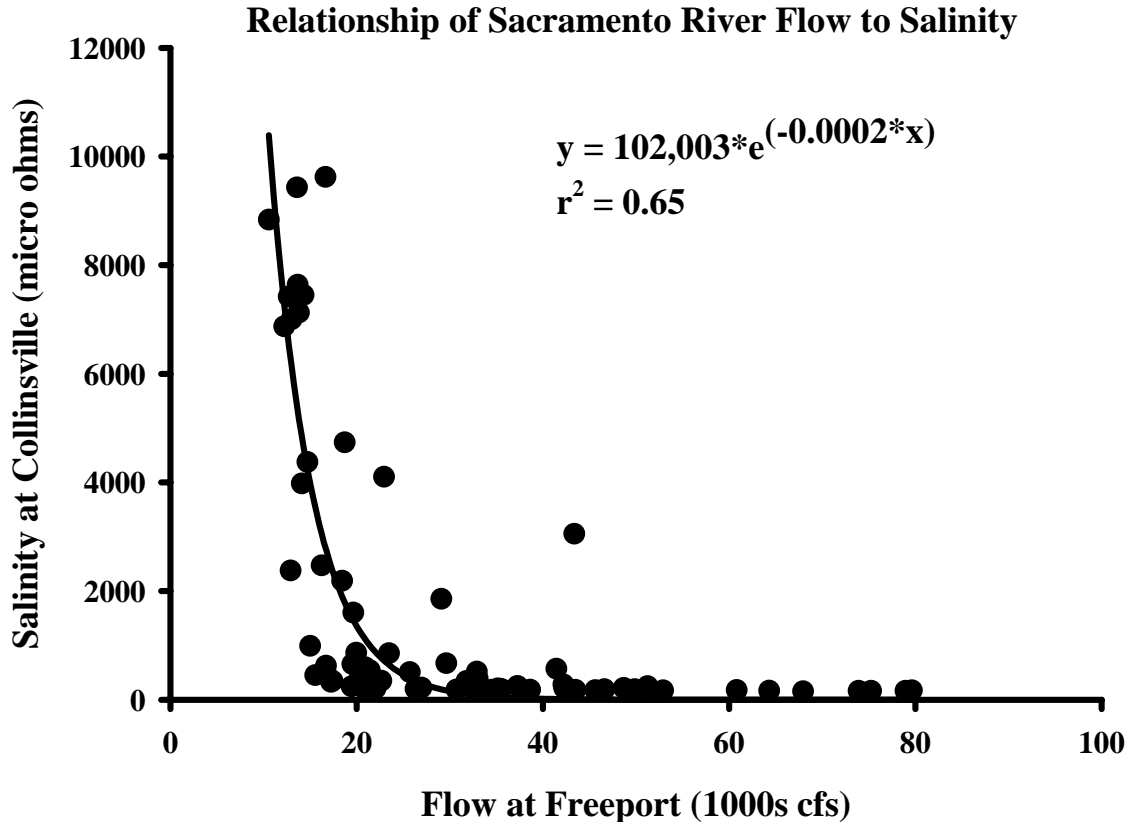


Figure 2. Relationship between Sacramento River flow and salinity in the Delta.

How do the different variables drive the survival estimates?

We analyzed the sensitivity of Delta survival estimates to environmental variables by varying one factor at a time. We examined the ranges for each variable that corresponded to the ranges in the dataset of Newman (2003). When we varied flow in this analysis, we concurrently changed salinity according to the equation presented in Figure 2. The sensitivity of temperature was not examined, because all temperatures in Newman's (2003) data set exceeded the range of temperatures that juvenile winter-run Chinook will encounter when passing through the Delta in December through March. The lowest temperature in the dataset of Newman was 58°F, which is near the upper boundary for optimal growth of juvenile Chinook in a natural setting. Thus, the dataset analyzed by Newman includes temperatures that ranged from the incipient lethal level in the mid 70's F, down to the optimum range for growth. There is little reason to expect that survival would continue to increase as temperature declined below 58°F, given that this is within the optimum range for growth. Therefore, we assumed there was no further benefit to smolt survival as temperature dropped below 58°F (i.e. we assumed the temperature effect was the same as that at 58°F).

The effects of each of the variables on the estimated Delta survival



can be seen in Figure 3. The most interesting result was the influence of flow and salinity on survival. As flow increases from a minimum of 6,000 cfs to 15,000 cfs survival decreases. Though flow has a positive effect on survival, increasing flow results in a decrease in salinity. Reductions in salinity cause decreases in survival. Only up to 15,000 cfs, do the effects of decreasing salinity out weight the positive effects of increasing flow. Salinity drops to near zero at flows above 20,000 cfs, and survival benefits of increasing flow begin to outweigh the effects of decreasing salinity at approximately 15,000 cfs. The relationships of the other variables to survival, as described by the Newman equation, are linear.

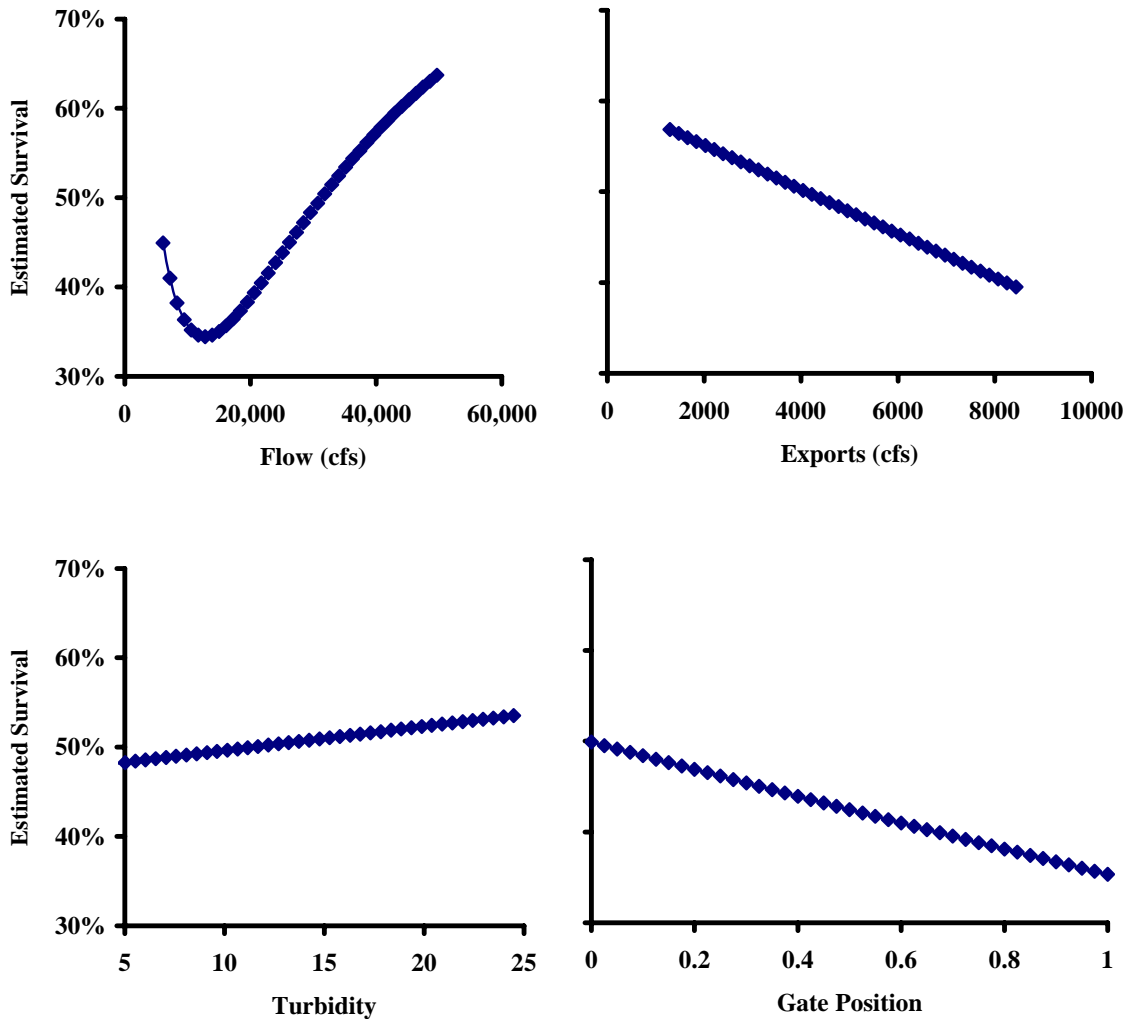


Figure 3. Change in Delta survival predicted by the adapted Newman function used in the IMF. One variable was varied while others were held at their mean value observed during paired releases of CWTs analyzed by Newman (2003). The effect of flow includes a link of flow to salinity according to the equation in Figure 1.



The survival equation just described requires for any simulation that values for environmental variables be supplied for the time frame when juvenile winter-run Chinook pass through the Delta. Because timing of peak migration varied between years, we next needed to account for differences in timing of winter-run smolt passage through the Delta each year.

When is Peak Migration Through the Delta?

Two peaks in outmigration of winter-run Chinook have generally been apparent each year since 1995-96 from captures of juveniles in the screw traps at Knights Landing, the trawl net at Sacramento, and the trawl net at Chipps Island (Figure 4). In each year, the first significant peak in passage followed the first major increase in flow during late-fall, generally in November or December. Regardless of flow changes, migration also consistently peaked a second time in March or early April, which we assume corresponds to the peak timing of the physiological transition from parr to smolt (seawater adaptation).

How was Survival of Two Migration Groups Modeled?

We accounted for the dual emigration peak in our test simulation of historic conditions by predicting survival for both groups, and averaging the survivals of those two groups. This was equivalent to assuming that half of the smolts passed following the first peak in flow, and the other half passed in March. The true pattern of emigration would have varied substantially from this assumption, but we have yet to develop a more accurate method of predicting smolt migration timing. Timing of passage at Sacramento has only been monitored since 1995-96, so migration timing in prior years was predicted from flows measured at Freeport. We assumed that migration patterns between 1968 and 1994 were similar to those of 1995-2002, in that there would have been a spike in migration following the first peak flow of the season. Passage data during 1995-2002 showed that the initial spike in migration each season lasted between 5 and 18 days following the first peak flow. Consistent with that duration, we predicted survival during the first peak in migration by using the mean values for environmental variables during the 10 days following the first sharp increase in flow. Survival during the second peak in migration that was typically in March [please show the data that make these two emigration periods apparent to everyone] was predicted using means for environmental variables during the full month of March each year.



Although river temperature was a key factor relating to passage survival in the data analyzed by Newman (2003), river temperatures during winter are nearly always lower than the lowest value (58°F) in the data set for fall Chinook used by Newman. Newman (2003) found that passage survival increased as river temperature decreased from 70°F to 58°F. It is doubtful that survival would have increased further as temperature dropped below 58°F, so we assumed the temperature effect at <58°F was the same as that for 58°F. For both migration groups, we assumed temperature was less than 58°F. Sporadic temperature recordings from the Sacramento River at Freeport during November and December of 1968-2002 showed that only 16 of 206 days exceeded 58°F, and the highest was 60.8°F. Of 138 readings in March, only 25 exceeded 58°F, and none exceeded 59.9°F. These data indicate it was reasonable assume average temperature in March was less than 58°F.

Predicted survivals for past years, and the environmental values they were based on, are presented in Figure 5 and Table 2.

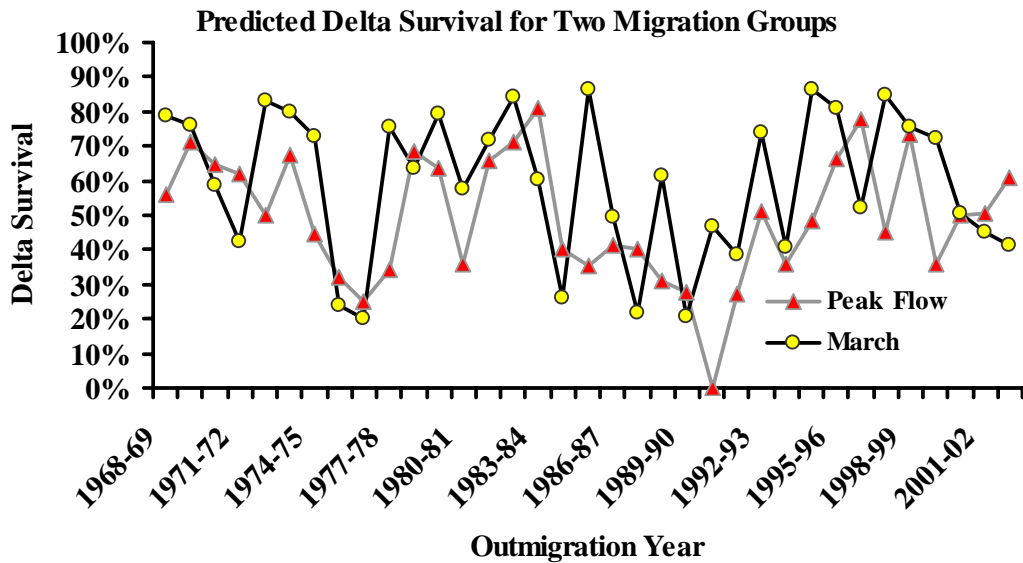


Figure 5. Predicted survival through the Delta during the two peaks in outmigration of winter-run Chinook smolts each year. “Peak flow” refers to the first peak and “March” refers to the second.



Table 2. Values for environmental variables used to predict Delta survival of winter-run Chinook smolts during the first peak (peak flow passage) and second peak (March) in outmigration, 1968-2002. Temperature was assumed to be less than 58°F in all instances. “Peak” and “March” values are 10 and 31-day averages, respectively.

Run Year	Peak Flow Passage Conditions								March Conditions					Total Survival	
	Start 10 days	Frpt. Q	Exports	Gates	Salinity	Turbidity	Survival	Survival	Frpt. Q	Exports	Gates	Salinity	Turbidity		Survival
1968-69	12-Dec	25,270	2,952	0.5	517	8.2	0.25	0.56	49,730	3,403	0.0	235	8.2	0.79	0.68
1969-70	13-Dec	29,810	1,102	0.0	221	8.2	0.92	0.71	44,210	2,265	0.2	158	8.2	0.76	0.74
1970-71	19-Nov	24,870	2,049	0.0	167	8.2	0.59	0.64	30,480	4,702	0.4	187	8.2	0.59	0.62
1971-72	23-Dec	27,550	1,497	0.5	212	8.2	0.48	0.62	23,900	6,601	0.7	172	8.2	0.42	0.52
1972-73	11-Nov	22,160	3,623	0.5	275	8.2	0.00	0.50	51,640	1,331	0.0	243	8.2	0.83	0.66
1973-74	8-Nov	44,350	5,014	0.5	327	8.2	0.73	0.68	64,680	6,200	0.0	140	8.2	0.80	0.74
1974-75	11-Nov	20,720	1,829	1.0	161	8.2	-0.21	0.45	50,940	6,061	0.2	172	8.2	0.73	0.59
1975-76	11-Nov	21,500	7,842	1.0	190	8.2	-0.75	0.32	14,570	8,410	1.0	2,224	8.2	0.24	0.28
1976-77	1-Jan	10,625	6,568	1.0	6,830	8.2	-1.10	0.25	6,573	3,724	1.0	7,281	8.2	0.20	0.22
1977-78	16-Dec	17,270	8,664	1.0	7,595	8.2	-0.65	0.34	55,570	5,773	0.2	194	8.2	0.75	0.55
1978-79	11-Jan	36,320	4,236	0.2	711	8.2	0.76	0.68	29,170	4,386	0.0	199	8.2	0.63	0.66
1979-80	24-Dec	36,870	6,430	0.2	475	8.2	0.55	0.63	55,340	4,441	0.0	203	8.2	0.80	0.72
1980-81	4-Dec	21,600	6,647	1.0	963	8.2	-0.58	0.36	24,510	4,862	0.0	254	8.2	0.58	0.47
1981-82	12-Nov	29,246	5,064	0.3	5,414	8.2	0.64	0.66	62,810	10,410	0.0	159	8.2	0.72	0.69
1982-83	18-Nov	41,510	5,231	0.0	127	8.2	0.92	0.71	78,290	5,429	0.0	189	8.2	0.84	0.78
1983-84	11-Nov	52,120	925	0.3	161	8.2	1.44	0.81	31,430	6,905	0.0	202	8.2	0.60	0.71
1984-85	8-Nov	23,580	8,186	0.6	677	8.2	-0.40	0.40	14,310	8,599	0.5	575	8.2	0.26	0.33
1985-86	24-Nov	17,400	9,460	0.7	6,445	8.2	-0.61	0.35	74,980	3,219	0.0	194	8.2	0.86	0.61
1986-87	4-Jan	15,200	6,290	0.0	1,523	8.2	-0.35	0.41	21,580	5,596	0.2	418	8.2	0.49	0.45
1987-88	3-Dec	19,150	7,005	1.0	6,984	8.2	-0.40	0.40	11,350	8,479	1.0	5,791	8.2	0.22	0.31
1988-89	24-Nov	17,240	8,795	0.9	4,580	8.2	-0.79	0.31	43,370	10,288	0.2	1,881	8.2	0.61	0.46
1989-90	21-Oct	16,960	10,643	1.0	6,089	8.2	-0.96	0.28	12,870	10,611	1.0	5,279	8.2	0.21	0.24
1990-91	none	--	--	--	--	--	--	--	25,760	9,794	0.3	2,975	8.2	0.47	0.47
1991-92	6-Jan	13,346	8,611	1.0	7,205	8.2	-0.99	0.27	20,340	10,490	0.0	326	8.2	0.38	0.33
1992-93	9-Dec	20,340	2,890	0.9	5,364	8.2	0.04	0.51	49,340	6,117	0.0	268	8.2	0.74	0.63
1993-94	7-Dec	23,860	10,686	1.0	5,272	8.2	-0.59	0.36	13,460	4,311	0.0	459	8.2	0.41	0.38
1994-95	4-Dec	20,660	6,132	0.5	4,782	8.2	-0.05	0.49	71,920	2,956	0.0	226	8.2	0.86	0.67
1995-96	18-Dec	31,820	4,360	0.0	148	8.2	0.67	0.66	56,240	3,677	0.0	136	8.2	0.81	0.74
1996-97	10-Dec	69,000	8,320	0.0	131	8.2	1.25	0.78	24,470	7,132	0.0	202	8.2	0.52	0.65
1997-98	24-Nov	22,400	10,785	0.2	5,493	8.2	-0.19	0.45	63,830	2,507	0.0	262	8.2	0.85	0.65
1998-99	23-Nov	33,680	1,654	0.0	134	8.2	1.01	0.73	56,840	7,223	0.0	167	8.2	0.75	0.74
1999-00	11-Jan	18,410	9,146	0.6	4,522	8.2	-0.57	0.36	58,560	9,152	0.0	171	8.2	0.72	0.54
2000-01	9-Jan	19,190	4,496	0.6	5,658	8.2	0.01	0.50	24,700	7,932	0.0	301	8.2	0.50	0.50
2001-02	24-Nov	19,690	5,291	0.5	5,563	8.2	0.02	0.50	21,320	8,276	0.0	317	8.2	0.45	0.48
2002-03	14-Dec	41,831	10,058	0.3	2,917	8.2	0.44	0.61	22,960	10,855	0.0	289	8.2	0.41	0.51



How do conditions during the paired CWT experiments analyzed by Newman compare to those during migration of winter-run smolts?

The current Delta survival function used in the IMF was developed using paired CWT release groups of fall-run Chinook. Though this method uses the best available data on smolt survival through the Delta, environmental conditions during emigration of fall-run Chinook generally differ from those during emigration of winter-run Chinook. Some parameters applied in the winter Chinook model are outside the range of observations used by Newman (2003). Because of our concern for predicting survival when environmental factors were outside the range of values analyzed by Newman, we examined the frequency with which winter conditions fell outside the range of analyzed data. We compared frequency distributions for environmental variables in the dataset analyzed by Newman to those for the period of Delta passage by winter-run Chinook smolts during 1968-2001. These comparisons were precautionary, to help us understand the extent that conditions for which we were predicting survival overlapped with the conditions used to develop the prediction function.

Sacramento River Flow

Sacramento River flow at Freeport during emigration of CWT groups evaluated by Newman (2003) ranged from 6,085 to 50,800 cubic feet per second (cfs). The frequency distribution of flow data indicates that CWT groups were generally released at flows between 5,000 and 15,000 cfs, with most at flows of 12,500 to 15,000 cfs (Figure 6). Few CWT groups were released at flows greater than 35,000 cfs (Figure 6), so the predicted increases in survival related to flows above 35,000 cfs should be accepted with caution. About one third of historic flows during winter-run smolt passage were greater than 35,000 cfs (Figure 4). We regard the survival effects of flow above 35,000 cfs as a critical uncertainty that needs testing.

Frequency Distribution of Flow Values

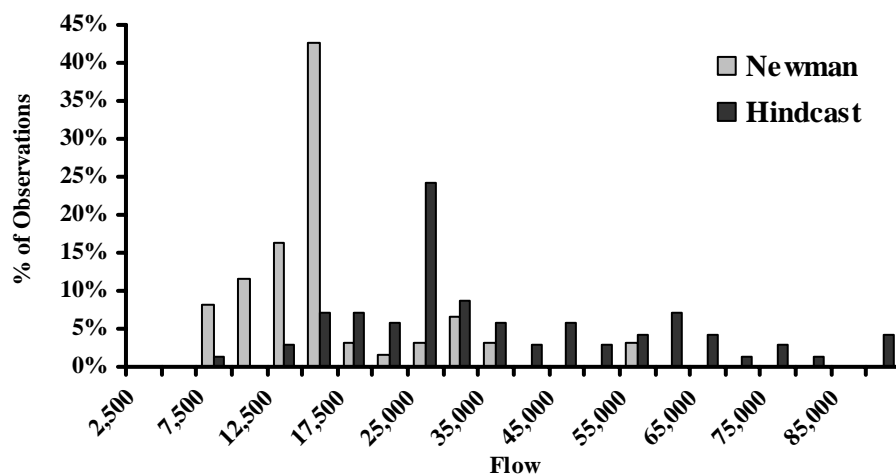


Figure 6. Frequency distributions of Sacramento River flows during the CWT releases analyzed by Newman (2003) compared to those used to predict historic values of Delta survival for winter-run Chinook smolts during 1968-2001.



Water Temperature

Water temperatures during the paired CWT releases analyzed by Newman (2003) ranged from 58°F to 76°F, while water temperatures during winter-run emigration (November through March) were nearly always <58°F. Water temperatures during the paired CWT releases were most often in the 61 - 64°F range, although temperatures in the upper 60's and low to mid 70's were common (Figure 7). The lowest and highest temperatures from the paired CWT data set were often associated with extremes in flow for the data set, i.e. low temperatures were generally associated with relatively high flows, and high temperatures with low flows.

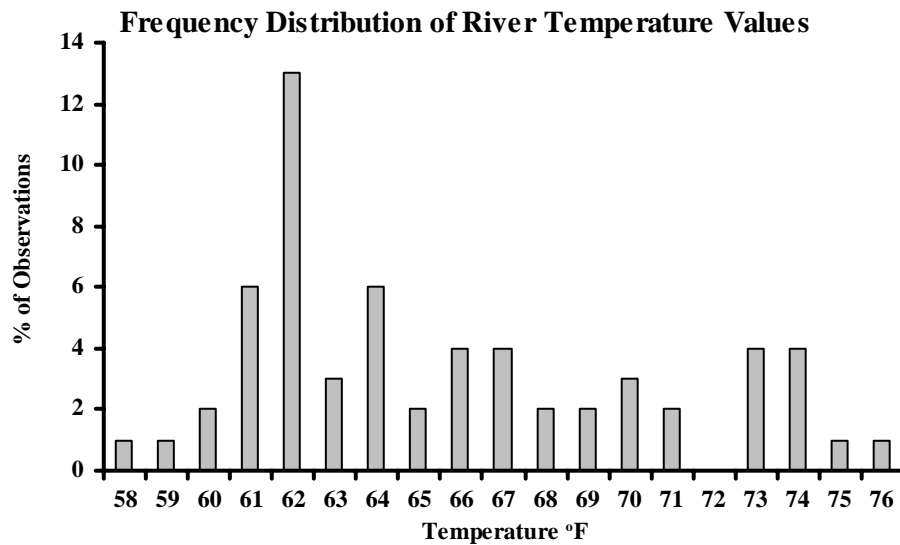


Figure 7. Frequency distribution of temperature observations used by Newman (2003) to estimate Delta survival.

Exports

Delta exports during emigration of CWT groups evaluated by Newman (2003) ranged from 1,289 to 6,821 cubic feet per second (cfs). The frequency distribution of export data indicates that CWT groups were generally released while exports were between 2,000 and 9,000 cfs (Figure 8).

Exports for the historic conditions that were simulated in the hindcast test of the IMF were generally similar to those in the data set analyzed by Newman (2003) (Figure 8). Only the occasional export rates exceeding 10,000 cfs during juvenile winter-run passage were outside the range of the Newman dataset. Thus, the Newman's coefficient for predicting the effect of exports on survival should be reasonable for winter-run Chinook, if there is little interaction of export rate with other environmental variables. The potential for interactive effects of exports and flow is high, so again, studies of survival at higher flows are needed to test the accuracy of predicted export effects on survival.

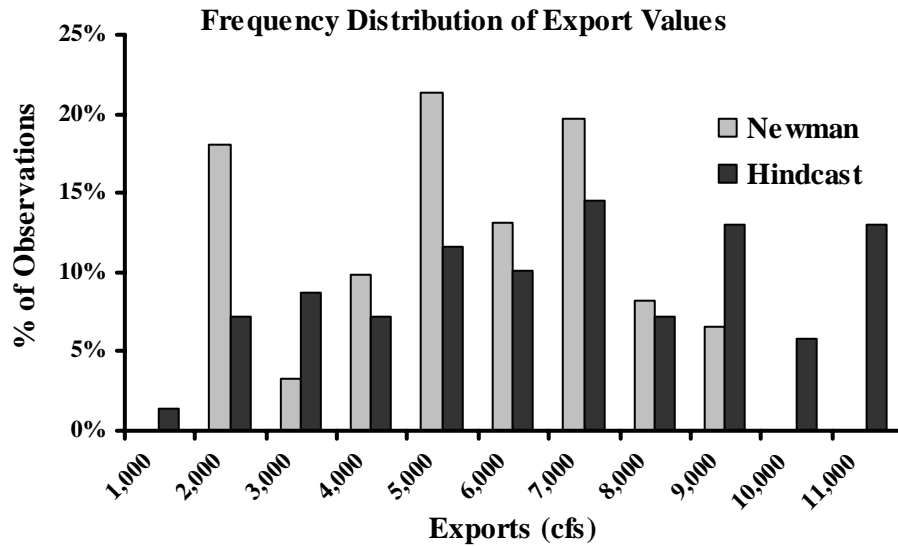


Figure 8. Frequency distribution of observed water export volumes in the dataset used by Newman (2003) and those used to predict historic values of Delta survival for winter-run Chinook smolts during 1968-2001.

Salinity

Salinity during emigration of CWT groups evaluated by Newman (2003) ranged from 160-12,873 μ mhos, and was most often less than 1,000 μ mhos. The same held true for historic values during outmigration of winter-run Chinook smolts. Thus, the coefficient for salinity in Newman's function (Table 1) should be appropriate for winter-run Chinook.

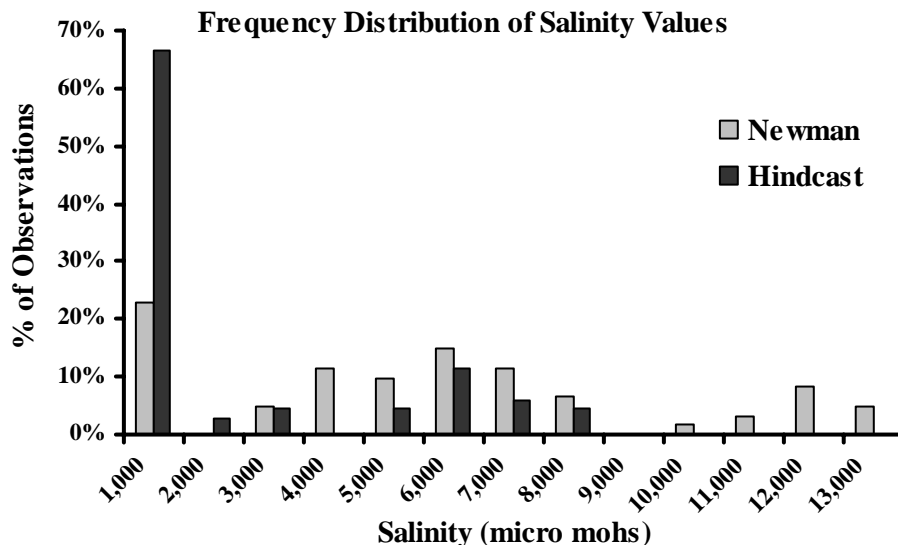


Figure 9. Frequency distribution of observed salinity in the dataset used by Newman (2003) and those used to predict historic values of Delta survival for winter-run Chinook smolts during 1968-2001. X-axis labels give upper bound of interval.



Alternative Evidence for Predicting Delta Survival in the Winter

We checked the reliability of the Newman (2003) function for predicting Delta survival in the winter by comparing its predictions to analyses and modeling of Brandes (personal communication, USFWS, Stockton) that were based on field experiments at the Delta Cross Channel (DCC) with late-fall-run Chinook during November to January. CWT experiments to evaluate effects of the DCC have been conducted in the Delta during November- January each winter since 1995. Data from those experiments provided an opportunity to check how well the observed smolt survivals during winter fit the predictions of the Newman equation, given the actual conditions that existed at the time of the late-fall CWT experiments. The results of this comparison, as will be described, indicate that the Newman equation can be used to predict survival through the Delta in the winter.

Experimental releases of late-fall Chinook near the DCC in November through January were not conducted so as to directly estimate overall of juvenile salmon survival through the Delta from Sacramento to Chipps Island (as the Newman equation does), but rather they provided ratios for expanded recovery rates in the Chipps Island trawl of fish passing through Georgiana Slough versus those passing down the main Sacramento River to Chipps Island. By making some simplifying assumptions, Pat Brandes (USFWS) was able to use the GS/Ryde recovery ratio in a five-step model to estimate survival from Sacramento to Chipps Island. Her model was based on the assumptions that (a) the proportion of juveniles following migration routes through the central Delta is equal to the proportion of Sacramento flow entering the central Delta, and that (b) Delta survival of juveniles continuing down the main stem Sacramento River to Chipps Island is constant at 80%. We compared the estimates from her model to predictions from the Newman equation to see if the results corroborated each other.

The model by Brandes to estimate survival of juvenile Chinook migrating through the Delta in winter used the following steps:

1. Because there was a limited number of tests performed with CWT groups, each at a discrete flow, Brandes needed first to quantify how survival varied across the continuous range of flows tested. To do this she regressed the GS/Ryde survival ratio from late-fall experiments on the export rates averaged for three days after release of each CWT group.
2. The regression in step 1 was then used to estimate the average GS/Ryde survival ratio for a given winter based on the mean export level between December 1 and April 15 that winter.
3. The proportion of smolts continuing down the main stem versus entering the Central Delta was assumed equal to the proportions of flow passing those two routes during the month of December.
4. The actual survival from Ryde to Chipps Island was assumed to be 80%, which is in the range of direct estimates in the spring, as calculated by Newman (2003).
5. Given the values calculated in steps 1-4, the survivals for the Interior Delta route



could be calculated and survivals from the two routes could be combined to estimate average survival through the Delta.

The equations and data used to complete the preceding five steps are described in more detail here. Experiments using late fall hatchery fish from Coleman National Fish Hatchery were used to estimate survival index ratios between fish migrating from Ryde and through the mainstem Sacramento and Georgiana Slough migration through the interior Delta. Brandes found that GS:Ryde survival index ratios were negatively correlated to average exports three days after release of the experimental groups, as defined by the equation:

$$\text{GS:R} = (3 \times 10^{-5}) * \text{Exports} + 0.4583$$

Where:

GS:R = Georgian Slough to Ryde survival index ratio

This relationship was subsequently used in the Brandes model to estimate Delta migration survival via the equation:

$$S = (S_M(P_M) + S_I(P_I))/100$$

and

$$S_I = (\text{G:R}) * S_M$$

Where:

S = Survival index of all migrants

S_M = Survival index of fish migrating through the mainstem (assumed to be 0.8)

S_I = Survival index of fish migrating through the interior Delta

P_M = Proportion of outmigrants migrating through the mainstem; assumed equal to the proportion of flow not diverted from the mainstem in December.

P_I = Proportion of outmigrants migrating through the interior Delta; assumed equal to the proportion of flow diverted from the mainstem in December.

Brandes estimated Delta survival of late fall Chinook via this model using the percent of water diverted in December and the mean exports between December 1 and April 15 for the migration years of 1995-96 to 2002-03. We compared the survival estimates of Brandes to Delta survival as estimated via the Newman equation under the same environmental conditions.

Survival estimates of the two methods were strongly and significantly correlated ($p < 0.001$; $r^2 = 0.80$) (Figure 10). This correlation of estimates from models developed with independent data indicates that both models capture similar variation due to the factors affecting late-fall run survival through the Delta. Although the Newman model predicts that survivals will reach higher highs and lower lows than the Brandes model, the two models correspond in predicting which conditions will produce high or low survival. The Brandes model is driven primarily by the assumptions that the proportion of outmigrants entering the interior Delta is equal to the proportion of flow diverted to the interior Delta, and that variation in the GS/Ryde recovery ratio during winter is driven by variation in survival only through the interior Delta (GS release groups). The Newman equation does not distinguish which fish take which route, and is driven primarily by total



flow, export flow, and DCC gate position. The corroboration of the two models lends support to assumptions made and relationships used within each model, and gives added credence to their respective results.

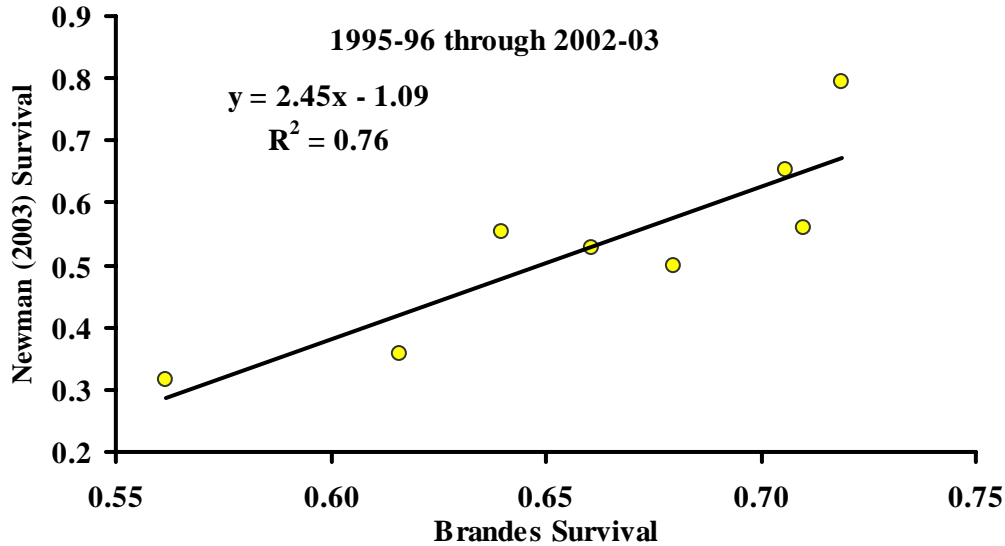


Figure 10. Relationship between survival predictions by the methods of Brandes vs those of Newman for winter-run Chinook smolts passing through the Delta during the winters of 1995-96 through 2002-03.

Table 3. Environmental values used in the Brandes and Newman models, and the associated estimates of survival for winter-run Chinook smolts passing through the Delta.

Year	Brandes		Newman						
	% Diverted	Survival	Flow (cfs)	Temp (F)	Exports	Gate Pos.	Salinity	Turbidity	Survival
1995-96	26	0.66	24,570	<58	5,143	0	853	8.2	0.82
1996-97	15	0.72	58,420	<58	5,418	0	469	8.2	0.95
1997-98	17	0.71	22,010	<58	4,858	0	1,398	8.2	0.75
1998-99	15	0.71	44,370	<58	9,000	0	108	8.2	0.95
1999-00	31	0.62	16,550	<58	7,550	1	3,716	8.2	0.62
2000-01	40	0.56	13,669	<58	7,687	1	7,893	8.2	0.41
2001-02	19	0.68	27,380	<58	9,234	0	930	8.2	0.83
2002-03	25	0.64	29189	<58	9,516	0	4,320	8.2	0.55

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