FINAL REPORT

PROJECT TITLE: **NEW METHODS FOR ANALYSIS OF CODED-WIRE TAG RECOVERY DATA**

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INTRODUCTION

Contemporary management of Pacific Salmon stocks within the jurisdiction of the Pacific Fishery Management Council relies substantially on analyses of recovery data from coded-wire tagged (CWT) fall chinook salmon released from public hatcheries. For Klamath River fall chinook salmon in particular, CWT recovery data have been used by the Klamath River Technical Advisory Team (KRTAT) to estimate time- and area-specific ocean fishery exploitation rates, annual ocean fishery exploitation rates, terminal fishery exploitation rates, and other life history parameters of interest (e.g. age-specific maturation probabilities).

Most of the methods that have been used by the KRTAT for analysis of CWT recovery data can be loosely termed "cohort analyses" (see, e.g., KRTAT 1990). These methods are based on an age-structured representation of the life history and fisheries for a fall chinook salmon stock (see, e.g., Hankin and Healey 1986). In these methods and throughout this report, the age of a salmon refers to the difference between brood year and year of recovery. Hankin and Healey (1986) assumed a "Type 1" ocean fishery (Ricker 1975). Thus, the biological year begins with the opening of ocean fishing for Klamath fall chinook salmon (usually May 1) and all mortality during the fishing season is assumed due to fishing. From the date that the fishing season ends, usually about September 1, until the beginning of the next fishing season, all mortality is assumed due to natural causes. Maturation is assumed to take place immediately after the fishing season, but before natural mortality. This last assumption is in rough agreement with freshwater run timing for most fall chinook salmon stocks. We use the term "conditional ocean survival rate" to refer to the fraction of fish that survive from the end of one fishing season until the beginning of the next fishing season because this rate applies only to fish that have survived the fishing season and did not mature (i.e. were not caught and did not enter freshwater). For brevity, we refer to these conditional ocean survival rates simply as ocean survival rates.

Hankin (1990, Appendix A) gave a detailed presentation of "cohort analysis" estimation methods for recovery data from a single release of CWT fall chinook salmon, and he presented many illustrations of their application to appropriate data sets, including those for Klamath River fall chinook salmon. (See Cramer 1990 for applications of these methods to CWT recovery data for Sacramento River chinook salmon). The cohort analysis begins at the oldest age of recovery (typically age 5 for Klamath River fall chinook), and catch and escapement at age 5 are added. This sum is then adjusted for natural mortality and added to estimated catch and escapement at age 4 to produce an estimate of the total number of age 4 fish alive immediately prior to the fishing season, A_4. Age 4 ocean fishery exploitation rate can now be estimated as age 4 ocean catch divided by the estimate of A_4, and this general process is continued "backwards" to age 2. Adjustments for natural mortality between each age are made by selection of particular values for ocean survival rates. Hankin (1990), Cramer (1990) and the KRTAT (1986) have typically assumed that ocean survival rates are 0.50 from age 2 to age 3, and are 0.80 for older age chinook.

The values of ocean survival rates that are assumed known in these cohort analyses are loosely based on tag recovery experiments in which chinook salmon from unknown stock mixtures were tagged in the ocean (Parker and Kirkness 1956, Cleaver 1969). When salmon are tagged in the ocean, subsequent "loss" of tagged fish may be attributed to three distinct causes (excluding violation of the usual tag recovery assumptions such as no tag loss): (1) capture in the ocean fishery, (2) maturation and return to freshwater, and (3) natural mortality. Although estimation of the catch of tagged fish in ocean fisheries may be accomplished through routine sampling programs, there are no collected sample data with which one might estimate freshwater escapement to an unknown number of freshwater systems. Thus, it is impossible to distinguish between losses due to natural mortality and losses due to maturation. As Hankin and Healey (1986) point out, natural mortality and maturation are confounded in ocean tag recovery data so that no unique estimate of survival rate is possible (unless one is willing to specify a particular maturation rate for tagged fish). Because age-specific maturation probabilities vary substantially both within and among chinook stocks (Nicholas and Hankin 1988, Hankin 1990) and the tagged stock mixture is unknown, there is no good basis for choice of any particular maturation rate to apply to ocean tag recovery data. The current assumed values for ocean survival rates appear to be based on Ricker's 1976 paper in which he concluded that the 65% survival rate guessed by Parker and Kirkness (1956) and Cleaver (1969) was probably too low. Thus, for example, Hankin and Healey (1986) generally assumed that the survival rate was 80%. We are not aware of any peer-reviewed publication that serves as the basis for an assumption that survival rates of chinook from age 2 to age 3 may be different from those at older ages (as assumed by the KRTAT, Hankin 1990, Cramer 1990), although this assumption does seem biologically plausible.

Throughout this report we will use the term "CWT recovery data" to refer to *estimated* catches and escapements of a CWT release group based on actual CWT recoveries in ocean fisheries and in freshwater. The cohort analysis methods described above generally use a very simple summary of these CWT recovery data. For a given CWT release group, summarized recovery data consist of (a) estimated ocean catches (sport plus commercial) at ages 2 through 5, and (b) estimated freshwater escapements (catch plus spawning escapement) at ages 2 through 5, for a total of 8 "observations" per release group. For an early-maturing stock such as Klamath River fall chinook salmon, essentially no recoveries are obtained after age 5 and we assume throughout this report that the age 5 maturation probability equals 1. Note that CWT recovery data sampling programs for most chinook salmon stocks are not adequate to allow meaningful estimation of fresh-water escapement. The extensive and ongoing freshwater sampling programs for returns of Klamath River fall chinook salmon are an important exception in this respect because they are specifically designed to produce estimates of total freshwater escapement.

For a given CWT release group, one might wish to estimate (a) ocean fishery exploitation rates at ages 2 through 5, (b) maturation probabilities at ages 2 through 4, (c) ocean survival rates from age i (i = 2, 3, 4) to age i+1, and (d) survival rate from release to age 2, immediately prior to ocean fisheries. In total, this gives 11 parameters for which estimates are desired. Thus, the number of parameters for which estimates are desired exceeds the number of data observations, in which case there can be no unique estimates of any model parameters. Viewed from this perspective, choice of assumed conditional ocean survival rates may be seen to be an expedient device which reduces the number of parameters for which estimates are desired to 8, equal to the number of observations.

In earlier work (Mohr and Hankin, unpublished) we found that the cohort analysis methods presented in Hankin (1990) are of maximum likelihood with respect to an assumed multinomial distribution of catches and escapements based on recovery data for a given CWT release group, *assuming that conditional ocean survival rates are known*. Estimates of all 8 parameters are unique in this case, and estimators have simple forms (see Hankin 1990, Appendix A). Because the number of observations is equal to the number of parameters to estimate, the estimation model is termed "fully saturated" and there are no "degrees of freedom" remaining for error. Given a known number of fish released from a particular release group, the observed recovery data (estimated catches and escapements at age) can be *perfectly* reproduced from estimated parameter values and CWT release group size.

There are no existing methods whereby estimates of all age-specific maturation probabilities and ocean fishery exploitation rates can be made from recovery data for a single CWT group *unless ocean survival rates are assumed known*. Further, there are no unbiased estimates of ocean survival rates in the published literature and there is general but undocumented belief among salmon biologists that ocean survival rates of salmon do vary and may have been unusually low during the 1983 El Nino event. Finally, assumption of any particular values for ocean survival rates in analysis of CWT recovery data may lead to substantial biases in estimates of life history and fishery parameters (see Part I, Summary of Estimation Methods).

In this report we present estimation methods which are instead based on statistical analysis of recovery data from a *sequence* of CWT groups of chinook salmon released from four or more successive brood years. If one makes a limited number of reasonable assumptions, it becomes possible to estimate ocean survival rates from CWT recovery data for such sequences of releases. Because the number of observations may exceed the number of parameters to be estimated in this context, differences between observed and predicted recovery data allow comparisons among alternative models and assumptions. Our estimation models share some features of the tag recovery models of Brownie et al. (1978, 1985), but they differ importantly in the complexity of model form and in the number of years for which fish from individual CWT release groups remain at large. Our proposed methods also allow for easy and informative inclusion of "replicate" CWT release groups from within the same brood year.

Because a formal presentation of our proposed estimation methods is likely to be of much less interest to most readers than the results of their application, immediately following this introduction we provide a brief listing of our most important findings and recommendations. The remainder of our report is organized into two distinct sections. In Part I we give a simplified overview of the methods we have developed for analysis of CWT recoveries from a sequence of release groups; this overview is intended to be accessible to most fishery biologists. We then present and discuss the application of these methods to CWT recovery data for fall chinook salmon released from Trinity River Hatchery (TRH) and Iron Gate Hatchery (IGH), 1978 through 1985 brood years. We conclude this section with a brief discussion of our most important findings and we consider areas for future research. In Part II, we present a very brief discussion of some important statistical matters that relate to development and application of our proposed estimation methods. In this section we make no attempt to make our presentation accessible to the "lay" reader, but we do assume that the reader has read the Summary of Estimation Methods in Part I. Material presented in Part II, when combined with computer data files and program listings contained in Appendices A and B, should allow an interested quantitative fishery scientist to explore the performance of the estimation methods we propose.

Finally, we wish to impress upon the reader that the proposed estimation methods and their example applications that are presented in this report should be regarded as ***preliminary***. To our knowledge, there are no existing CWT analysis methods that are analogous to those presented in this report, and the methods that we present and discuss have not yet been subjected to peer review by qualified statisticians. There are many areas of uncertainty in the application of our proposed methods, and we have pointed some of these out as appropriate in this report. Also, we must warn that application of our proposed methods requires specialized statistical analysis software and at least a 386-based PC with at least 4 MB of free memory (or a comparable time-sharing computing environment). Despite these reservations and warnings, we have been very encouraged by the preliminary applications of our proposed methods to CWT recovery data for Klamath River fall chinook salmon. We believe that our proposed methods will be found to have substantial merit after they have been more thoroughly developed and subjected to peer review.

SUMMARY AND RECOMMENDATIONS

Methods

1. Given a minimum of four successive brood years' release of fall chinook salmon, at a similar time, size and location, one may estimate life history and fishery parameters of interest from CWT recovery data *without assuming that conditional ocean survival rates are known.*

2. Our proposed methods share many similarities with existing models for tag recovery analysis, but differ in important respects due to the unusual and complicated nature of the life histories of and fisheries for chinook salmon.

3. Our proposed methods may be extended to include an indefinite number of brood years' release of CWT fish, and may easily incorporate CWT recovery data from "true replicate" groups.

4. Application of our proposed methods may be accomplished using specialized but commercially available software packages (such as **BMDP, SAS**) and may be carried out in a PC environment, although at least a 386-based PC with 4 MB of free RAM is required.

Results of Applications

1. We applied our proposed methods to CWT recovery data (estimated ocean catches and freshwater escapements) for fall chinook salmon released from Trinity River Hatchery (TRH) and Iron Gate Hatchery (IGH), brood years 1978 through 1985. Application of our proposed methods to recovery data for fingerling fall chinook salmon produced implausible and unstable estimates of model parameters. We suspect that this poor performance for fingerling release groups reflects the inherent variation in CWT recovery data for fingerling releases due to inconsistent and generally poor survival.

2. Application of our proposed methods to CWT recovery data for yearling fall chinook salmon released from IGH produced plausible and stable estimates of life history and fishery parameters, and allowed selection of an "appropriate" model. This model assumes that all CWT groups share the same age 4 maturation probability, but allows conditional ocean annual survival rates of age 2 and older fall chinook salmon to vary between years. We assumed that this same model applied to CWT recovery data for TRH yearling chinook salmon.

3. We found no statistical evidence for a difference in ocean survival rates of age 2 as compared to age 3 and older fall chinook salmon based on CWT recovery data for IGH yearling releases.

4. Estimated survival rates from release to age 2 ranged from less than 1% to at least 40% for both IGH and TRH releases, and estimated ocean survival rates ranged from approximately 15% to 100% for both IGH and TRH releases, over the period of years spanned by 1978-1985 brood year releases.

5. Estimates of survival rates from release to age 2 were extremely poor for 1981 brood year fish released in fall of 1982, and estimates of ocean survival rates for age 2 and older chinook salmon were extremely poor for the fall/spring period of 1982/83. These periods of extremely poor survival correspond to the peak of the 1983 El Nino event.

6. Estimates of age-specific maturation probabilities confirmed that although both IGH and TRH races are early-maturing (age 4 maturation probabilities are in excess of 90%), tendency for precocious maturation and for maturation at age 3 is much more pronounced for TRH fish than for IGH fish. Interannual variation in age-specific maturation probabilities was especially large for TRH fall chinook salmon for which age 3 maturation probabilities ranged from less than 10% to nearly 100% over the 1978-85 brood years.

7. The substantial variation in ocean survival rates, combined with the substantial variation in estimated age 2 and age 3 maturation probabilities have substantial implications for management of Klamath River fall chinook salmon in general, and for prediction of preseason abundance in particular. Current preseason prediction methods invoke implicit and untenable assumptions that age-specific maturation probabilities do not vary between years or among races for Klamath River chinook salmon.

Recommendations

1. Preseason predictions of the abundance of Klamath River chinook salmon should be modified so as to account for interannual variation in maturation probabilities at ages 2 and 3 and, if possible to account for stock composition (e.g. IGH vs TRH "races"). A substantial amount of this interannual variation may be attributable to variation in size at age.

2. We provisionally recommend that large (100,000 - 150,000) CWT releases of yearling fall chinook salmon from IGH and TRH, that have routinely been released as a single group with a single tag code, be released instead as two true replicate CWT groups of 50,000 - 75,000 fish per group, each group receiving a distinct tag code. Based on our preliminary analyses of CWT recovery data for IGH (some replicated groups) and TRH (no replicated groups) releases of yearlings, replication appears to improve stability of estimated life history and fishery parameters and allows better identification of appropriate model.

PART I

SUMMARY OF ESTIMATION METHODS

As discussed in the Introduction, it is impossible to estimate survival rate from release to age 2, and age-specific maturation probabilities or ocean fishery exploitation rates from CWT recovery data for a single release group *unless one assumes that (conditional) ocean survival rates are known*. Choice of ocean survival rates may in turn have substantial impact on estimated life history parameters. For example, suppose that 100,000 fall chinook salmon were released as yearlings from IGH and that ocean fishery catches and escapements (freshwater catch + spawning escapement) were as follows:

Age	Ocean Catch	Freshwater Escapement
2	12	68
3	1,546	1,336
4	1,237	1,088
5	5	12

Label age-specific maturation probabilities as σ_i (i = 2, 3, 4,), age-specific ocean fishery exploitation rates as u_i (i = 2, ..., 5), and survival from release to age 2 as S_0. The table below illustrates the dependence of estimates of these parameters on choices of the assumed ocean survival rates if the single CWT release group methods of Hankin (1990, Appendix A) are used. For simplicity, the illustration assumes that ocean survival rates, S, are the same at all ages (i.e. the survival rate from age 2 to age 3 is the same as the survival rate from age 3 to 4, and from age 4 to 5).

Estimated	Assumed Values of Ocean Survival Rates at ages 2-4			
Parameter	S = 0.40	S = 0.50	S = 0.65	S = 0.80
u_2	0.0005	0.0008	0.0012	0.0016
u_3	0.1757	0.2034	0.2379	0.2659
u_4	0.5225	0.5244	0.5261	0.5272
u_5	0.2941	0.2941	0.2941	0.2941
σ_2	0.0031	0.0045	0.0068	0.0093
σ_3	0.1842	0.2207	0.2697	0.3130
σ_4	0.9624	0.9697	0.9765	0.9808
S_0	0.4416	0.3056	0.2016	0.1470

Note that parameter estimates at earlier ages are more affected by choice of ocean survival rate than are estimates at older ages. For example, estimates of age 5 exploitation rates are independent of assumed choices of survival rates, whereas estimates of maturation probabilities and exploitation rates at age 2 and of survival rate to age 2 display an approximately 3-fold range of values according to choice of survival rate. Clearly, it would be desirable to estimate life history and fishery parameters from CWT recovery data *without* making some guesses of the unknown ocean survival rates.

Brownie et al. (1978, 1985) presented estimation methods for analysis of tag recovery data from a sequence of annual releases of M_i tagged fish ($i = 1, 2, \ldots, s$). Tags must allow identification of year of release (as do coded-wire tags). For their methods, it is simplest to let the recovery data be equal to the number of tags that are returned each year by anglers. Label these recovery data as R_{ij}, where i denotes year of release and j denotes year of recovery ($j = 1, 2, \ldots, k$) . A recovery data "array" may be visually displayed by the following table:

Year of Release (i)	Number Released	Year of Recovery (j)			
		1	2	3	4
1	M_1	R_{11}	R_{12}	R_{13}	R_{14}
2	M_2		R_{22}	R_{23}	R_{24}
3	M_3			R_{33}	R_{34}
4	M_4				R_{44}

Although in the above table the number of years of release is equal to the number of years of recovery (i.e. $k = s$), recoveries may continue for many years beyond tag releases (i.e. $k > s$).

Define the *annual recovery rate*, r_i, as the fraction of the fish alive at the beginning of a year for which tags are recovered. The tag recovery models assume that this recovery rate applies to all groups at large during a particular year of recovery, although this rate may vary between years. Thus, the *expected* number of recoveries from a particular release group in a particular year is equal to the product of the *recovery rate*, r_j, in that year and the number of animals from that release group which are alive at the beginning of the recovery year. The number of animals from a particular release group that are alive at the beginning of a recovery year depends on the assumed survival situation. For example, if annual survival rates are assumed constant and are independent of age of animal, then the expected number of animals from the first release group that are alive at the beginning of the third recovery year would be

$M_1 \cdot S \cdot S$, and the expected number of recoveries from the first release group during the third year would be $E(R_{13}) = r_3 M_1 S^2$. Similar expected value calculations for other recovery entries give the following array of *expected* recoveries:

Year of Release	Number Released	Year of Recovery 1	2	3	4
1	M_1	r_1M_1	r_2M_1S	$r_3M_1S^2$	$r_4M_1S^3$
2	M_2		r_2M_2	r_3M_2S	$r_4M_2S^2$
3	M_3			r_3M_3	r_4M_3S
4	M_4				r_4M_4

In the above table of expected values, note that *within* a given the column all entries depend on the same recovery rate; thus a total of four recovery entries provide information on the recovery rate in the fourth year, r_4. Similarly, all recovery entries that are not on the main diagonal (and are not of the form r_iM_i) depend on the same assumed constant survival rate and hence provide information on its value. It is this "linking" or "sharing" of common recovery rates and survival rates across release groups and across years of recovery that allows survival rates and recovery rates to be estimated.

Suppose, for example, that we instead had recovery data from just a single release group and that we were interested in estimation of the survival rate. The recoveries from this group during its first year at large, R_{11}, would be uninformative because they do not depend on S. The expected recoveries in the second year do depend on S, but they also depend on the recovery rate in the second year, r_2. Thus, unless r_2 is assumed known, there is no way to estimate S from the recoveries of a single release group in recovery year two. Equivalently, unless S is assumed known, it is impossible to estimate r_2. The parameters r_2 and S are said to be "confounded", in the same sense that it is impossible to estimate survival rates of salmon based on tagging of fish in the ocean because losses due to natural mortality and maturation are confounded and cannot be statistically separated.

If there is a second year of tagged releases, however, the recoveries from the second release group in the second recovery year, R_{22}, would allow estimation of r_2 as R_{22}/M_2. This estimate of r_2 could then be used to obtain an estimate of S from the recoveries of the first group during the second recovery year. Thus, the problem of confounding of r_2 with S for a single release group can be avoided by releasing a second release group from which an estimate of r_2 can be obtained, thus allow statistical separation of the parameters r_2 and S.

One very important alternative set of assumptions regarding these same recovery data is to assume that annual survival rates vary between years but are the same for all release groups in year j. In this case, we label annual survival rates by S_j and the array of expected recoveries will look like the table below:

Year of Release	Number Released	Year of Recovery, j			
		1	2	3	4
1	M_1	r_1M_1	$r_2M_1S_1$	$r_3M_1S_1S_2$	$r_4M_1S_1S_2S_3$
2	M_2		r_2M_2	$r_3M_2S_2$	$r_4M_2S_2S_3$
3	M_3			r_3M_3	$r_4M_3S_3$
4	M_4				r_4M_4

Note that, for this alternative model of the recovery data structure, information concerning a particular annual recovery rate is again contained in the column entries for that particular recovery year. Information regarding survival rates, however, now has a much more complicated pattern than for the previous model. For example, all information concerning survival during the second year is contained in the upper right most four cells (R_{13}, R_{14}, R_{23} and R_{24}); only the first and second release groups were exposed to survival conditions during the second year so that recoveries from successive release groups are not informative with respect to S_2.

Brownie et al. (1978, 1985) presented different sets of estimators for these alternative models, and they also presented statistical tests whereby an "appropriate" model could be selected. These tests are based essentially on a comparison between a weighted sum of the squared differences between observed and predicted recovery data for one model as compared to some alternative and simpler model. That is, given estimates of r_i and S for the first model (constant survival), it is possible to *predict* the values of the R_{ij} for each entry in the recovery data array. For example, letting carats or "hats" denote estimated quantities or parameters,

$$\hat{R}_{23} = \hat{r}_3 \cdot M_2 \cdot \hat{S} \ .$$

For the second model (in which annual survival rates vary between years), R_{23} would be predicted as:

$$\hat{R}_{23} = \hat{r}_3 \cdot M_2 \cdot \hat{S}_2 \ .$$

Each set of predicted values could then be compared to the actual collected recovery data, R_{ij}, and a (weighted) sum of the squared differences between observed and predicted could be calculated. If the sum for the simpler model (constant S) were (essentially) no greater than for the more complex model (variable S_i), one would conclude that there was no statistical evidence in support of the more complex model; thus, the simpler model would be judged "appropriate". Alternatively, if the sum for the simpler model were much larger than for the more complex model, one would instead conclude that the more complex model was appropriate.

The methods that we propose for analysis of CWT recovery data for chinook salmon share many similarities with the tag recovery models of Brownie et al. (1978, 1985), but they are also different in many important respects. First, recoveries from a sequence of CWT releases of fall chinook salmon produce two recovery data arrays and these are of a different "shape" than those considered in the tag recovery models (Table 1). If all salmon are assumed to mature at age 5, then ocean recoveries from a particular group will take place for only four years at ages 2 through 5. This feature gives the recovery data arrays a shape which is very different from the tag recovery models in which all release groups are assumed at large in any given recovery year (for $j > i$). Second, the entries in the arrays are *estimated* total ocean catches and total freshwater escapements rather than raw recovery data as in the tag recovery models. Finally, underlying structure of all of our alternative models reflects the age-structured and complex nature of the life history and fisheries for fall chinook salmon. In this respect our models are far more complicated than the tag recovery models considered by Brownie et al.

Nevertheless, our proposed methods for analysis of CWT recovery data for chinook salmon are similar to those of tag recovery models in several important respects. First, measures of the differences between observed and predicted catches and escapements allow comparison among alternative models. Second, application of our methods requires a minimum of four successive brood years of CWT releases. If the number of entries in the columns of the arrays of Table 1 are listed, they give the characteristic pattern: 1, 2, 3, 4, 4, ... 4, 4, 3, 2, 1. No matter how many years that releases take place, there are never recoveries from more than four brood years of releases during any single recovery year. A minimum of four brood years of CWT releases is needed to achieve this general pattern enclosed by the boxes in Table 1 (column totals in this case will be 1, 2, 3, 4, 3, 2, 1). For the tag recovery models, a minimum of three years of releases is required for goodness of fit tests (Brownie et al. 1978, Model 1). Finally, even with the sequential CWT release group approach, certain parameters prove to be confounded with one another. For example, the expected values of ocean catches and freshwater escapement of the first group at age 2 are:

Table 1. Illustration of the layout of estimated catches and escapements based on recovery data from a sequence of CWT release groups beginning with the 1978 brood. Boxed areas indicate minimal recovery data requirements for methods used in this report. Estimated catches are identified by Y's and subscripts indicate release group number and age at capture. Thus, Y_{23} indicates estimated catch from the second release group (1979 brood) at age 3 (in 1982). Estimated escapements are identified by E's and subscripts indicate release group number and age at escapement.

Ocean Catches

Brood Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
	Year of Recovery										
1978	Y_{12}	Y_{13}	Y_{14}	Y_{15}							
1979		Y_{22}	Y_{23}	Y_{24}	Y_{25}						
1980			Y_{32}	Y_{33}	Y_{34}	Y_{35}					
1981				Y_{42}	Y_{43}	Y_{44}	Y_{45}				
1982					Y_{52}	Y_{53}	Y_{54}	Y_{55}			
1983						Y_{62}	Y_{63}	Y_{64}	Y_{65}		
1984							Y_{72}	Y_{73}	Y_{74}	Y_{75}	
1985								Y_{82}	Y_{83}	Y_{84}	Y_{85}

Escapements

Brood Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
	Year of Recovery										
1978	E_{12}	E_{13}	E_{14}	E_{15}							
1979		E_{22}	E_{23}	E_{24}	E_{25}						
1980			E_{32}	E_{33}	E_{34}	E_{35}					
1981				E_{42}	E_{43}	E_{44}	E_{45}				
1982					E_{52}	E_{53}	E_{54}	E_{55}			
1983						E_{62}	E_{63}	E_{64}	E_{65}		
1984							E_{72}	E_{73}	E_{74}	E_{75}	
1985								E_{82}	E_{83}	E_{84}	E_{85}

$$E(Y_{12}) = u_{12} \cdot N_1 \cdot S_{10}, \text{ and}$$

$$E(E_{12}) = \sigma_{12} \cdot (1-u_{12}) \cdot N_1 \cdot S_{10},$$

where u_{12} is the ocean fishery exploitation rate for the first release group at age 2; σ_{12} is the maturation probability for the first release group at age 2; S_{10} is the survival rate from release until age 2, immediately before the ocean fishing season, for the first age group; and N_1 is the number of CWT fish released from the first group. No expected values for any other recovery data entries depend on u_{12} or on the intensity of the ocean fishery during 1980. Thus, the model parameters u_{12} and S_{10} are confounded and only their product (which we label P_1) may be uniquely estimated. The three factors σ_{12}, $(1-u_{12})$ and S_{10} are also confounded in the expected value for E_{12} and only their product (which we label P_2) can be uniquely estimated. In the tag recovery models, when the number of years of recovery exceeds the number of years of release, estimates of annual recovery rate and annual survival rate become confounded for recovery years greater than or equal to the last year of release.

If the fate of each of four successive CWT release groups were entirely unrelated to one another, then there would be a total of 4·11 (44) parameters to estimate. The number of observations would only be 4·8 (32) and it would be impossible to obtain unique estimates of parameters of interest. It is therefore necessary to make some simplifying assumptions concerning relationships among model parameters. The most important simplifying assumptions that we make for all model alternatives concern relations among ocean fishery exploitation rates (u_{ij}) of age 2, 3, and 4 fish and may be expressed in mathematical terms by:

(1) $$u_{i2} = u_{i-1,3}^{\,r_2} \text{ ; and}$$

(2) $$u_{i-1,3} = u_{i-2,4}^{\,r_3} \text{ ; so that}$$

(3) $$u_{i2} = u_{i-2,4}^{\,r_2 r_3} .$$

In the above formulas, i denotes brood year of release, j denotes age (j = 2, 3, 4) and r_2 and r_3 are constants which scale exploitation rates between ages during fishing seasons. These assumptions are most easily understood with reference to a particular brood year, i. For example, the assumptions state that (1) the age 2 exploitation rate for fish from the 1980 brood year release is equal to the age 3 exploitation rate for fish from the 1979 brood year release *raised to the r_2 power*, and (2) the exploitation rate for age 3 fish from the 1979 brood year release is equal to the age 4 exploitation rate for fish from the 1978 brood year release *raised to the r_3 power*. Thus, (3) the exploitation rate for age 2 fish from the 1980 brood year release is also equal to the exploitation rate for age 4 fish from the 1978 brood year release *raised to the* $r_2 \cdot r_3$ *power*.

The "sense" of these assumptions may be most easily understood by reference to Table 1. Note that the third column of ocean catches lists the estimated catches at age 4 from fish released from the 1978 brood year, the estimated catches at age 3 from fish released from the 1979 brood year, and the estimated catches at age 2 of fish released from the 1980 brood year. Thus, each of these catches took place during the *same* fishing season. Equations (1) - (3) basically argue that age-specific ocean fishery exploitation rates have a simple relationship to one another *within a particular fishing season*. We also assume that this same simple relation holds *in all recovery years*. The magnitude of the age 4 exploitation rate may, of course, vary between years and will affect the magnitude of the exploitation rates at ages 2 and 3 in that same year.

We also make the important assumption that age 5 ocean fishery exploitation rates are the same as age 4 ocean fishery exploitation rates in the same fishing season. Because so few Klamath River fall chinook salmon are alive at age 5 and very few are caught in ocean fisheries, it is essentially impossible to estimate age 5 exploitation rate in any case.

The significance of these assumptions regarding exploitation rates is that they reduce the number of exploitation rate parameters that need to be estimated from 16 (four for each group) to 6 (u_{13}, u_{14}, u_{24}, u_{34}, u_{44} and u_{45}) plus the two additional parameters r_2 and r_3. As mentioned previously, the parameter u_{12} is confounded with S_{10} and cannot be uniquely estimated. Together, this reduction by 8 in the number of parameters that must be estimated leaves a total of 36 parameters to estimate as compared with 32 observations; the estimation model is still "oversaturated" and unique estimates of model parameters still cannot be calculated.

The remaining assumptions that we make ensure that the estimation model is not oversaturated and allow us to compare among alternative models. Table 2 lists those simplifying assumptions that we have made and the corresponding model parameters that need to be estimated. The smallest number of model parameters in Table 2 are listed for Model 1; for this alternative model all groups are assumed to share the same age 4 maturation probability and the ocean survival rate is assumed the same in all years and at all ages. The largest number of model parameters listed in Table 2 is for Model 5; for this alternative model each group has its own unique set of maturation probabilities at all ages, ocean survival rates vary with years, and the ocean survival rates of fish from age 2 to age 3 may be different from those of older aged fish.

Table 2. Alternative assumptions and corresponding parameters that must be estimated for alternative models of recovery data for CWT fall chinook salmon, one CWT group released from each of four successive brood years. Alternatives are listed from the simplest to the most complex and are identified model number (e.g. Model 1). Subscripts on age-specific exploitation rates, u_{ij}, and on age-specific maturation probabilities, σ_{ij}, indicate release year and age; first subscript on survival rates from release to age 2, S_{i0}, indicates release year; subscripts on ocean survival rates, S_j, indicate recovery year j (fall of year j to spring of year j+1) or fish age (Model 2 only). P_3 is a confounded parameter equal to $(1-u_{12})(1-\sigma_{12})S_{10}$ for Models 1 and 2; and equal to $S_2(1-u_{12})(1-\sigma_{12})S_{10}$ for Models 3, 4 and 5. σ_{44} and S_7 are probably confounded for Models 4 and 5, but were not treated as such.

Model 1

Assumptions:

1. All groups share the same common age 4 maturation probability;
2. Ocean survival rates are independent of age and year.

Parameters: σ_{13}, σ_{22}, σ_{23}, σ_{32}, σ_{33}, σ_{42}, σ_{43}, σ_{44},
u_{13}, u_{14}, u_{24}, u_{34}, u_{44}, u_{45},
S, r_2, r_3, P_1, P_2, P_3,
S_{20}, S_{30}, S_{40}.

Model 2

Assumptions:

1. All groups share the same common age 4 maturation probability;
2. Ocean survival rates are independent of year, but survival rate from age 2 to age 3 is different than survival rate of older fish.

Parameters: σ_{13}, σ_{22}, σ_{23}, σ_{32}, σ_{33}, σ_{42}, σ_{43}, σ_{44},
u_{13}, u_{14}, u_{24}, u_{34}, u_{44}, u_{45},
S_2, S_3, r_2, r_3, P_1, P_2, P_3,
S_{20}, S_{30}, S_{40}.

Model 3

Assumptions:

1. All groups share the same common age 4 maturation probability;
2. Ocean survival rates are independent of age but may vary with year.

Parameters: σ_{13}, σ_{22}, σ_{23}, σ_{32}, σ_{33}, σ_{42}, σ_{43}, σ_{44},
u_{13}, u_{14}, u_{24}, u_{34}, u_{44}, u_{45},
S_2, S_3, S_4, S_5, S_6, S_7, S_8, r_2, r_3, P_1, P_2, P_3,
S_{20}, S_{30}, S_{40}.

Table 2 (Continued). Alternative assumptions and corresponding parameters that must be estimated for alternative models of recovery data for CWT fall chinook salmon, one CWT group released from each of four successive brood years. Alternatives are listed from the simplest to the most complex and are identified model number (e.g. Model 1). Subscripts on age-specific exploitation rates, u_{ij}, and on age-specific maturation probabilities, σ_{ij}, indicate release year and age; first subscript on survival rates from release to age 2, S_{i0}, indicates release year; subscripts on ocean survival rates, S_j, indicate recovery year j (fall of year j to spring of year j+1) or fish age (Model 2 only). P_3 is a confounded parameter equal to $(1-u_{12})(1-\sigma_{12})S_{10}$ for Models 1 and 2; and equal to $S_2(1-u_{12})(1-\sigma_{12})S_{10}$ for Models 3, 4 and 5. σ_{44} and S_7 are probably confounded for Models 4 and 5, but were not treated as such.

<u>Model 4</u>
Assumptions:

1. Ocean survival rates are independent of age but may vary with year.

Parameters: σ_{13}, σ_{22}, σ_{23}, σ_{24}, σ_{32}, σ_{33}, σ_{34}, σ_{42}, σ_{43}, σ_{44},
u_{13}, u_{14}, u_{24}, u_{34}, u_{44}, u_{45},
S_2, S_3, S_4, S_5, S_6, S_7, S_8, r_2, r_3, P_1, P_2, P_3,
S_{20}, S_{30}, S_{40}.

<u>Model 5</u>
Assumptions:

1. Ocean survival rates may vary with year, but in any given year the survival rate of fish from age 2 to age 3 is different from the survival rate of older age fish according to the relation:

$$S_{j2} = S_j^Q ,$$

where S_j denotes the survival rate for age 3 and older fish during recovery year j, Q is a constant factor by which survival of age 2 fish is related to survival of older fish, and S_{j2} denotes survival rate for age 2 fish in year j.

Parameters: σ_{13}, σ_{22}, σ_{23}, σ_{24}, σ_{32}, σ_{33}, σ_{34}, σ_{42}, σ_{43}, σ_{44},
u_{13}, u_{14}, u_{24}, u_{34}, u_{44}, u_{45},
S_2, S_3, S_4, S_5, S_6, S_7, S_8, r_2, r_3, Q, P_1, P_2, P_3,
S_{20}, S_{30}, S_{40}.

If there are true "replicate" groups of CWT fish released from any given brood year, recovery data for such groups can be easily included in estimation methods. As our estimation methods are currently formulated, however, the groups must be *true* replicates in the sense that we assume that they share identical life history and fishery parameters, including survival rate from release to age two, and differ only in the CWT code that they receive. It may be possible in the future to also include "partial replicates" - groups for which survival to age 2 may differ, but for which all other parameters may be assumed the same. Because full replicate groups are assumed to share identical life history and fishery parameters, inclusion of recovery data for such groups serves only to augment the number of observations and to increase the number of degrees of freedom for estimating model "error" and comparing among alternative models. Replication thus appears intrinsically valuable for our proposed methods, but we have not addressed this formally as yet.

Estimation of model parameters involves three basic steps. The first step is to construct a data file which lists the numbers of fish from each CWT group that are estimated caught in ocean fisheries or escaped to freshwater at age, and the corresponding number of fish released from each such group (Appendix A, I). The second step is to construct a computer program appropriate for estimation of the parameters of a particular alternative model (see Table 2). (Appendix A, II, provides programs appropriate for Model 1, Model 2, Model 3 and Model 4 for the four brood year case, and Appendix B, II, provides programs for "Model 1", "Model 3", and "Model 4" for the 8 brood year case.) Note that these computer programs must provide initial guesses for all parameters to be estimated, as is typical of nonlinear regression programs. The final step is to run such a program in a suitable statistical computing environment, such as the "Nonlinear Regression" program **3R** in BMDP/386. BMDP uses an iteratively-reweighted least-squares algorithm to arrive at the maximum likelihood estimates of all model parameters, according to those weights supplied by the user. Also supplied by the user is a "loss function" criterion (or *deviance*) which is specified to allow measurement of the nature of errors between observed and predicted recovery data (based on maximum likelihood estimates of model parameters) and to allow comparison among alternative models. Details concerning choice of weights and the loss function are presented in Part II of this report.

APPLICATIONS OF METHODS AND RESULTS

Data Sets and Imposed Constraints

We applied our methods to summarized recovery data for fall chinook salmon released with CWT from IGH and TRH, brood years 1978 through 1985. At least four successive brood years' releases of CWT groups were made for fingerlings (generally June release of subyearlings at 4-8 g/fish) and "yearlings" (generally October/November release of subyearlings at 40-60 g/fish) at both hatcheries. Although true yearling CWT releases (fish released in April at age 1+) have been made from TRH, they have not been made for four successive brood years. Thus, recovery data for true yearling releases could not be subjected to our proposed methods. CWT recovery data for 1979 through 1985 brood year CWT release groups were provided by Alan Barraco (pers. comm., File KLAMFAL.WK1). Recovery data for 1978 brood year CWT releases were from Hankin and Diamond (1984).

Application of our estimation methods to all sets of four brood year groups of CWT recovery data (with no replication) for fingerling releases of fall chinook salmon from Iron Gate and Trinity River Hatcheries failed to generate results which consistently identified the same "appropriate" model, and calculated estimates were often implausible (e.g. survival rates from age 2 to age 3 greatly exceeded survival rates of older fish for Model 2). For these reasons, we have not presented any results for fingerling release groups. Recovery data may be too "sparse" to allow stable estimation of model parameters due to generally low and highly erratic survival of these releases to age 2. We did not subject fingerling data to the full 8 group analysis method, however, and it is possible that this procedure might produce plausible parameter estimates.

For applications of our methods to TRH releases of yearling fall chinook salmon, we found no groups that could be considered replicates during any brood year. Thus, CWT recovery data for all groups of four brood years were limited to exactly 32 observations. For IGH releases of yearling fall chinook salmon in several brood years, however, we treated "diet study" groups (which were released at identical or nearly identical mean weights) as if they were true replicates. In these instances, summaries of CWT recovery data generally suggested very little difference between survival rates of diet groups from a particular brood year, and there was no obvious reason to suspect that diet would affect subsequent life history or fishery parameters. We emphasize that these groups are not "true replicates" in the sense discussed previously. Nevertheless, we believed they were sufficiently similar to true replicates to treat them as such. Doing so also allowed us to examine the performance of our estimation methods where data sets have (IGH) or do not have (TRH) replicate groups. We also applied our estimation methods to CWT recovery data from all 8 brood years simultaneously, thus including the full recovery data arrays depicted in Table 1.

To ensure that our estimation methods produced parameter estimates that were always positive, we constrained all estimates of maturation probabilities, ocean fishery exploitation rates, and annual ocean survival rates between 0 and 1. We constrained our estimates of survival from release to age 2 between 0 and

0.40, thus ruling out rates in excess of 40% which we felt, *a priori*, would be unreasonable. Finally, we constrained the parameters r_2 and r_3 between 0 and 10; in retrospect we feel it was probably not necessary to constrain these two parameters. Other than these generally reasonable constraints, we imposed no other assumptions on the estimation process with the important exception of specification of the underlying estimation model.

Selection of Appropriate Model

We found in all cases that model "lack of fit" (deviance - see Part II) could not be distinguished between Model 1 and Model 2, and between Model 4 and Model 5. Thus, our estimation methods provided no statistical evidence in support of a *consistent* difference between ocean survival rates from age 2 to age 3 as compared to those for older aged fish. This does not necessarily mean that differences between survival rates do not exist between ages. Differences between age groups may be too small to detect given the errors of estimation of survival rates, or relative differences between age groups may not vary according to the assumption made in Table 2 (see Models 2 and 5). Accordingly, we present no results for these two alternative models (Model 2 and Model 5).

Table 3 shows that F statistics for selecting among the remaining 3 alternative models (Model 1, Model 3, and Model 4) were non-significant in all comparisons between Model 4 (the "full model") and Model 3. From this we conclude that our analyses suggest that, for both IGH and TRH races of fall chinook salmon, there is little statistical evidence in support of interannual variation in maturation probability at age 4. (Recall that Model 3 assumes that all groups share a common age 4 maturation probability, whereas Model 4 allows each group to have a unique age 4 maturation probability.)

F statistics for comparing models Model 1 and Model 3 resulted in clear significance ($P \leq 0.01$) in 4 of 5 comparisons for IGH fall chinook salmon, but in no case (0/5) for TRH fall chinook salmon. Note, however, that the degrees of freedom for these F statistics were considerably larger for the comparisons between IGH groups than for the TRH groups. From these comparisons we conclude that Model 3 model appears most appropriate for IGH releases of yearling fall chinook salmon. For the TRH CWT yearling groups, on purely statistical grounds one might conclude that Model 1 is generally appropriate (i.e. that annual ocean survival rates do not vary), but we suspect that this conclusion may principally reflect the lack of replication among TRH releases of CWT fall chinook salmon. Also, we suspect, on *a priori* grounds, that it is unreasonable to suppose that ocean survival rates of chinook salmon do not vary between years. We therefore assume that Model 3 is most appropriate for TRH fall chinook salmon.

Table 3. Approximate F statistics for comparisons among alternative models for IGH and TRH releases of yearling fall chinook salmon, based on four successive years' releases. Estimates of dispersion parameter for F statistics, ϕ_t, are based on an assumed full model for which annual ocean survival rates and age four maturation probabilities vary between years (Model 4). Best estimates of dispersion parameter, ϕ^*, are based on the reduced model (Model 3) for which ocean survival rates vary, but for which age four maturation probabilities are the same for all groups. The simplest model (Model 1) assumes that annual ocean survival rates and age four maturation probabilities are the same for all groups. Number of data observations is indicated by **n** and reflects degree of replication of releases; n = 32 indicates no replication. **Brood** indicates first year of four years used for calculations; thus, 1978 refers to brood years 1978 through 1981. Degrees of freedom for F statistics are (3, **n**-30) for comparisons of Model 3 with Model 4, and (4, **n**-30) for comparisons of Model 1 with Model 3. Probabilities of F statistics are listed in parentheses).

Facility	Brood	n	ϕ_t	F statistics 3 vs 4	F statistics 1 vs 3	ϕ^*
IGH	1978	48	16.40	0.76 (0.53)	4.37 (0.012)	15.84
IGH	1979	64	14.19	0.39 (0.76)	13.97 (0.0000)	13.49
IGH	1980	88	13.95	1.95 (0.13)	6.25 (0.0003)	14.60
IGH	1981	88	13.31	1.91 (0.14)	6.22 (0.0003)	13.91
IGH	1982	72	15.89	0.93 (0.43)	1.77 (0.15)	18.49
TRH	1978	32	18.15	0.39 (0.78)	0.81 (0.62)	12.92
TRH	1979	32	8.55	0.38 (0.78)	3.62 (0.23)	16.76
TRH	1980	32	23.00	0.30 (0.83)	0.95 (0.57)	17.11
TRH	1981	32	45.60	0.23 (0.87)	0.09 (0.98)	19.70
TRH	1982	32	3.30	5.74 (0.15)	0.37 (0.82)	12.68

When all 8 brood years (1978 through 1985) of CWT releases of yearling fall chinook salmon are subjected to simultaneous analysis, Models 1, 3 and 4 have 39, 47 and 54 parameters, respectively. (Parameters are all listed in the Appendix B computer program.) F statistics, degrees of freedom (in parentheses), and related measures for comparing among alternative models (listed as in Table 3) were as follows:

Facility	Brood	n	ϕ_t	F statistics: 3 vs 4	F statistics: 1 vs 3	ϕ^*
IGH	1978-85	120	17.37	0.57 (7,66)	4.71 (8,66)	16.67
TRH	1978-85	64	13.04	0.59 (7,10)	1.67 (8,10)	10.82

For IGH data, these F statistics clearly argue that Model 3 is again appropriate. For TRH data, F statistics were again both non-significant, although the F-statistic for the comparison between Model 1 and Model 3 was fairly unlikely (P = 0.22). From these comparisons we again conclude that Model 3 is most appropriate for IGH fall chinook salmon. For the sake of consistency, we assume that this conclusion also applies to the TRH CWT recovery data for yearlings, despite the inconclusive F statistic in support of this conclusion.

Predicted recovery data based on model parameter estimates generally appeared to match well with observed recovery data, although occasional substantial differences were noted even with the supposedly "appropriate" Model 3. For example, Table 4 lists observed and expected recovery data for one four brood year CWT data set for IGH yearling fall chinook salmon. Substantial discrepancies may be noted for Y_{33} and for most escapements at age 4. Discrepancies among age 4 escapements may reflect our choice of appropriate model because all groups are assumed to share the same age four maturation probability for Model 3.

Parameter Estimates

Table 5 contrasts estimated survival rates from release to age 2 and ocean survival rates based on all sets of four brood year CWT yearling releases of IGH fall chinook salmon. For the particular parameters presented in Table 4, agreement of parameter estimates between groups appeared relatively good, if imperfect. For example, S_{40} was estimated as 0.008 for the first set of four brood years, S_{30} was estimated as 0.008 for the second set of four brood years, and S_{20} was estimated as 0.008 for the third set of four brood years; in each case, these estimates correspond to survival from release to age 2 for 1981 brood year releases.

Table 4. Example of observed (**OBS**) recovery data and predicted recovery data (**PRE**). Data set is I78ALLY.DAT (as in Appendix A), IGH releases of yearling fall chinook salmon, brood years 1978 through 1981. Model assumptions are that age 4 maturation probability does not vary by brood year, but annual ocean survival rates vary between years (Model 3). Estimated catches are identified by Y's and subscripts indicates release group number and age at capture. Thus, Y_{23} indicates estimated catch from the second release group (1979 brood) at age 3 (in 1982). Estimated escapements are identified by E's and subscripts indicate release group number and age at escapement. Thus, E_{45} indicates estimated escapement of the fourth release group (1981 brood) at age 5 (in 1986). **STDRES** denotes standardized residuals (**[OBS-PRE]/√PRE**). Multiple entries for same code label reflect "replicate" groups released from the 1981 brood year. Note that release group sizes were not equal for 1981 brood year "replicate" groups.

Code	OBS	PRE	STDRES	Code	OBS	PRE	STDRES
Y_{12}	0	0.02	- 0.14	Y_{42}	2	0.71	1.53
Y_{13}	2508	2475.84	0.65	Y_{43}	26	20.55	1.20
Y_{14}	1778	1882.99	- 2.42	Y_{44}	86	49.48	5.19
Y_{15}	6	14.58	- 2.25	Y_{45}	0	0.00	0.00
E_{12}	19	19.00	0.00	E_{42}	1	0.63	0.47
E_{13}	415	415.73	- 0.04	E_{43}	21	21.31	- 0.07
E_{14}	1122	1049.32	2.24	E_{44}	168	109.69	5.57
E_{15}	17	7.53	3.45	E_{45}	4	1.06	2.94
Y_{22}	5	14.96	- 2.58	Y_{42}	0	1.83	- 1.35
Y_{23}	1030	1009.34	0.65	Y_{43}	72	52.51	2.69
Y_{24}	744	594.67	6.12	Y_{44}	106	126.45	- 1.82
Y_{25}	5	16.86	- 2.89	Y_{45}	0	0.00	0.00
E_{22}	29	28.97	0.01	E_{42}	2	1.61	0.31
E_{23}	272	271.44	0.03	E_{43}	57	54.46	0.34
E_{24}	159	275.64	- 7.03	E_{44}	200	280.31	- 4.80
E_{25}	4	14.63	- 2.78	E_{45}	1	2.69	- 1.03
Y_{32}	20	8.80	3.78	Y_{42}	2	0.86	1.23
Y_{33}	166	252.68	- 5.45	Y_{43}	21	24.72	- 0.75
Y_{34}	400	408.68	- 0.43	Y_{44}	47	59.53	- 1.62
Y_{35}	7	10.48	- 1.07	Y_{45}	0	0.00	0.00
E_{32}	67	67.11	- 0.01	E_{42}	0	0.76	- 0.87
E_{33}	202	187.14	1.09	E_{43}	21	25.64	- 0.92
E_{34}	368	318.23	2.79	E_{44}	131	131.96	- 0.08
E_{35}	49	25.88	4.54	E_{45}	0	1.26	- 1.12

Table 5. Estimated survival rates from release to age 2 (S_{i0}) and estimated ocean survival rates (S_j) for CWT fall chinook salmon released from IGH as yearlings during October or November. Each set of estimates is based on releases made in four successive years. Thus, IGH78-81 reflects estimates for yearling releases from the 1978 through 1981 brood years. Estimates of 1.000 and 0.400 are equal to the imposed constraints for indicated parameters. Accepted model assumes equal age 4 maturation probabilities across groups, but allows annual ocean survival rates to vary (Model 3). (Note that the estimated survival rate during the seventh year, S_7, may have such a large error of estimation as to be meaningless.)

	Estimated Parameters for Indicated Groups				
Parameter	IGH78-81	IGH79-82	IGH80-83	IGH81-84	IGH82-85
Survival to Age 2					
S_{20}	0.400	0.041	0.008	0.147	0.400
S_{30}	0.076	0.008	0.120	0.400	0.134
S_{40}	0.008	0.400	0.400	0.049	0.059
Ocean Survival Rate					
S_3	0.170	0.343	1.000	0.820	0.196
S_4	0.185	1.000	1.000	0.122	0.482
S_5	1.000	1.000	0.121	0.870	0.442
S_6	1.000	0.033	0.860	0.810	1.000
S_7	0.084	0.086	0.816	1.000	0.382

In contrast, for 1982 brood year releases a similar comparison gives 0.400, 0.120, and 0.147 for three different sets of four brood years each; although these estimates would all be regarded as "high" relative to 0.008, they are clearly not all the same. Similar comparisons of ocean survival rate estimates across groups can be made and reveal the same general but imperfect agreement. In the remainder of this report we therefore present only estimates which are based on the full 8 brood year data sets for both Iron Gate and Trinity River hatchery releases of fall chinook salmon as yearlings. Only a single estimate of each model parameter is possible when data from all groups are subjected to simultaneous analysis.

Appendix Tables C1 through C6 present point estimates and approximate confidence limits for survival rates to age 2, ocean survival rates, age-specific maturation probabilities, and age 4 ocean fishery exploitation rates for 1978 through 1985 brood year CWT releases of yearling fall chinook salmon from Iron Gate and Trinity River hatcheries for Model 3 based on all eight groups. In this Results section we instead present graphical summaries of these data.

Survival rates from release to age 2 demonstrated extreme variation across brood years for both IGH and TRH CWT yearling releases of fall chinook salmon, and the pattern of survival rate with brood year was in strong agreement between the two hatcheries (Figure 1). Survival rates were extremely good in two years, reaching the 40% imposed constraint for the 1979 and 1983 brood years for both hatcheries, and survival rate was extremely poor (less than 1%) for the 1981 brood for both hatcheries.

A similar and also dramatic variation in ocean survival rates between years was indicated for fish released from both hatcheries and there was general, if imperfect, agreement in the trend of estimates for the two stocks (Figure 2). Ocean survival rates were extremely good for both stocks during the fall/spring periods of 1983/84, 1984/85, and 1988/89. Ocean survival rates were extremely poor (point estimates less than 30%) for both stocks during the fall/spring periods of 1981/82, 1982/83, and 1985/86. Agreement between stocks was less good for fall/spring periods 1986/87, 1987/88 and 1989/90. However, as documented in Appendix Tables C1 and C4, approximate 95% confidence intervals were extremely large for all of those estimates of survival rate which might be classified as "favorable" (greater than about 40%), and no interval estimates were possible for estimates equal to the constraint of 1. Thus, the relatively poor agreement between stocks for certain "favorable" fall/spring periods may not be real because errors of estimation of these "favorable" survival rates are so large. In contrast, errors of estimation of survival rates for those periods during which survival rates would be classified as "poor" were usually small. For example,

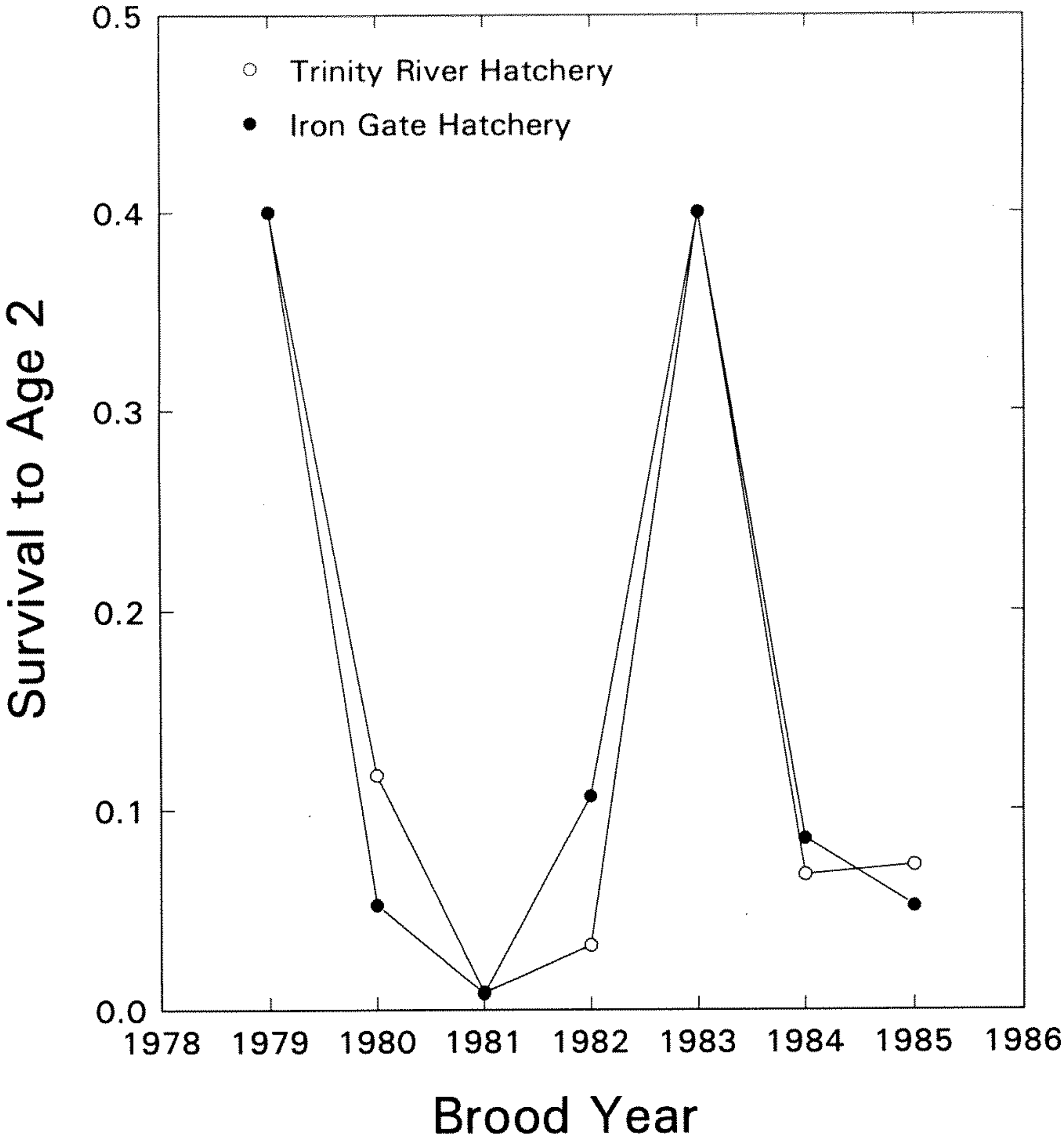

Figure 1. Survival rates from release to age 2 for fall chinook salmon released from IGH and TRH, 1978 - 1985 brood years.

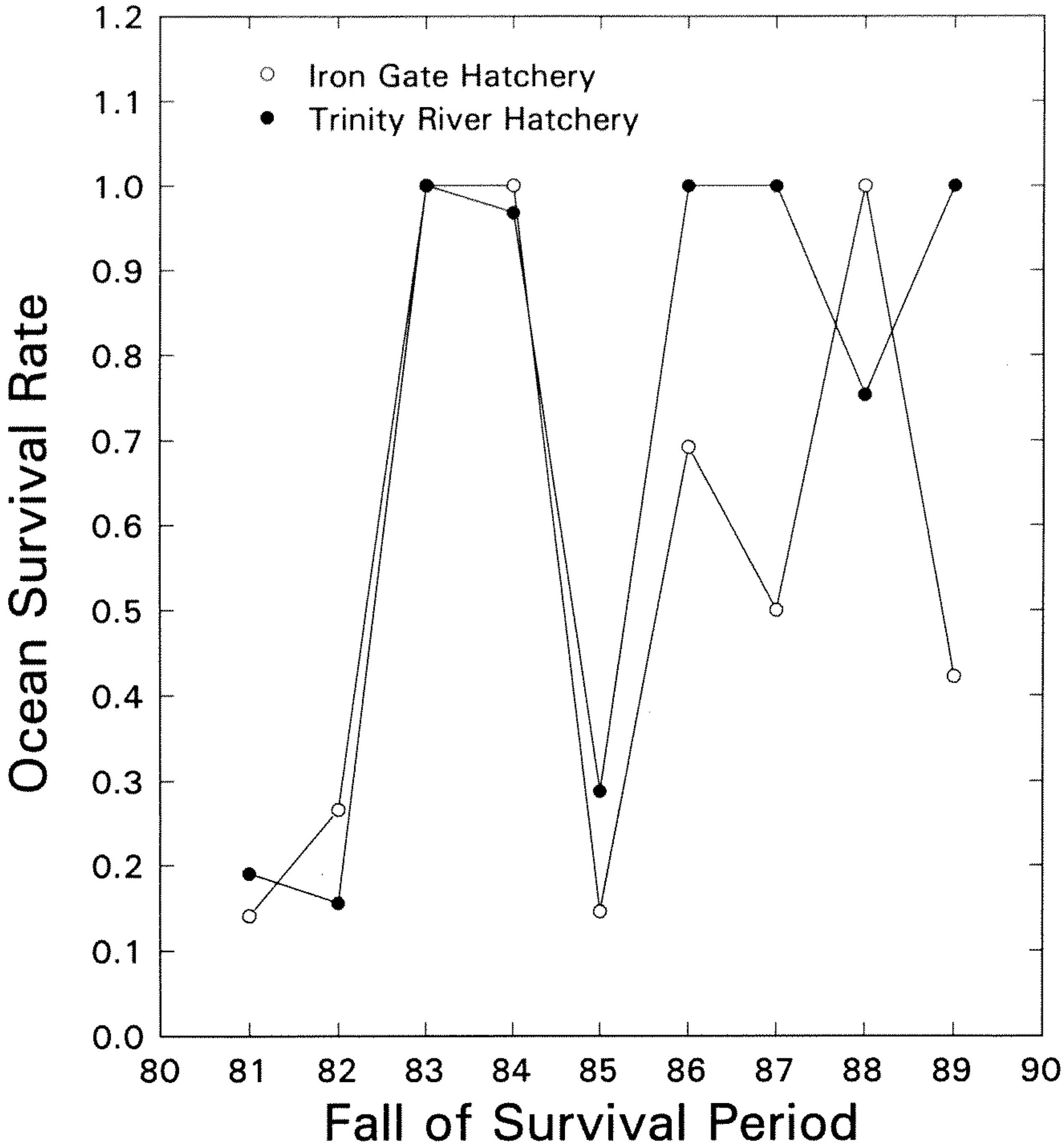

Figure 2. Estimated conditional ocean survival rates from fall of year i to spring of year i+1 for fall chinook salmon released as yearlings from IGH and TRH, 1978 - 1985 brood years.

95% confidence intervals for the estimated survival rates during the fall/spring period of 1982/83 were 0.09 - 0.44 for IGH fish and 0.05 - 0.26 for TRH fish; for the 1985/86 period analogous intervals were 0.08 - 0.21 and 0.27 - 0.31 for IGH and TRH fish, respectively.

Estimates of annual ocean fishery exploitation rates for age 4 chinook salmon released as yearlings from IGH and TRH generally ranged from 40% to 60% over the 1982 through 1989 fishing seasons (Figure 3). Although Figure 3 suggests that age 4 exploitation rates for TRH fish may generally be less than those for IGH fish, 95% confidence intervals for estimated exploitation rates had substantial overlap in all but one year (Appendix Tables C2 and C5). For both stocks, the most striking feature is the relative lack of trend in estimated ocean fishery exploitation rate given the continually greater restrictions imposed on the ocean fishery by the Pacific Fishery Management Council from 1982 through 1989.

Estimated maturation probabilities of IGH and TRH releases of fall chinook salmon showed substantial differences between stocks and generally followed those trends earlier described by Hankin (1985, 1990) based on cohort analysis methods for which annual ocean survival rates are assumed known. At age 2, maturation probabilities for IGH releases ranged from near zero to slightly more than 1%, whereas maturation probabilities ranged from about 1% to more than 8% for TRH releases (Figure 4). At age 3, maturation probabilities for IGH fish ranged from about 2% to almost 20%, whereas maturation probabilities for TRH releases ranged from about 10% to 100% (Figure 5). Although interannual variation in estimated maturation probabilities would probably be considered "large" for both stocks, this variation seems much more substantial for TRH fish than for IGH fish. There was no clear evidence of synchronous variation in maturation probabilities at age between stocks, although maturation probabilities were unusually large for both stocks for 1980 brood releases.

Approximate 95% confidence intervals for estimated maturation probabilities were generally quite small for most IGH and TRH release groups at age 2 and age 3, although some age 3 maturation probabilities were poorly identified for TRH fish (Appendix Tables C3 and C6). For example, a "typical" 95% confidence interval for the age 2 maturation probability of IGH releases was 0 - 0.03, whereas a "poor" 95% confidence interval for the age 3 maturation probability was indicated by the 1985 brood year TRH releases for which the interval was 0.20 - 0.92. Errors of estimation of maturation probabilities did not, however, appear directly related to the magnitude of the estimated probability. For example, the 95% confidence interval for age 3 maturation probability of the 1983 brood release from TRH was 0.72 - 0.78, and the 95% confidence intervals for age 4 maturation probabilities were 0.98 - 1.0 and 0.89 - 0.96 for TRH and IGH stocks, respectively.

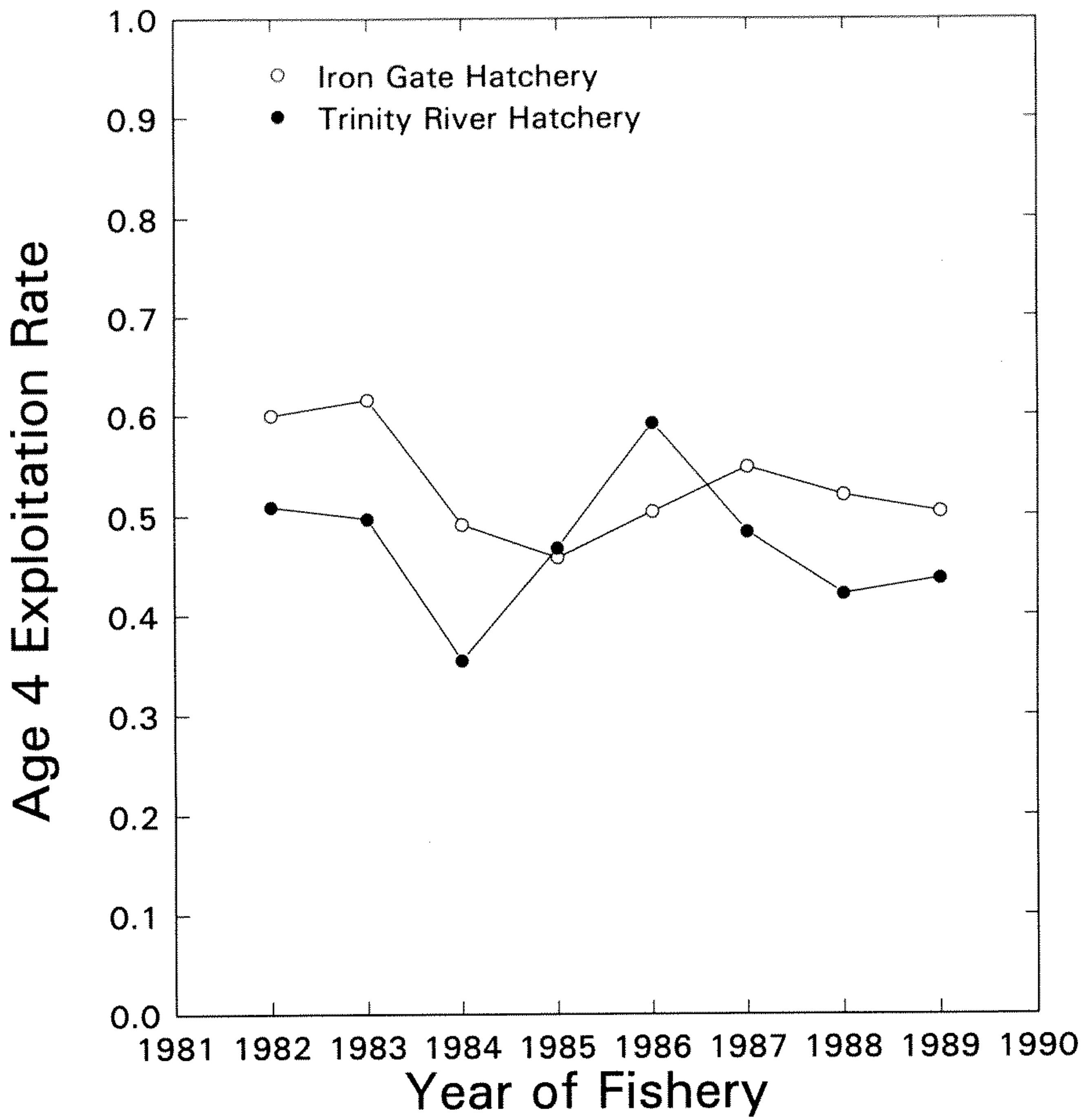

Figure 3. Estimated age 4 ocean fishery exploitation rates for TRH and IGH releases of fall chinook salmon, brood years 1978 - 1985.

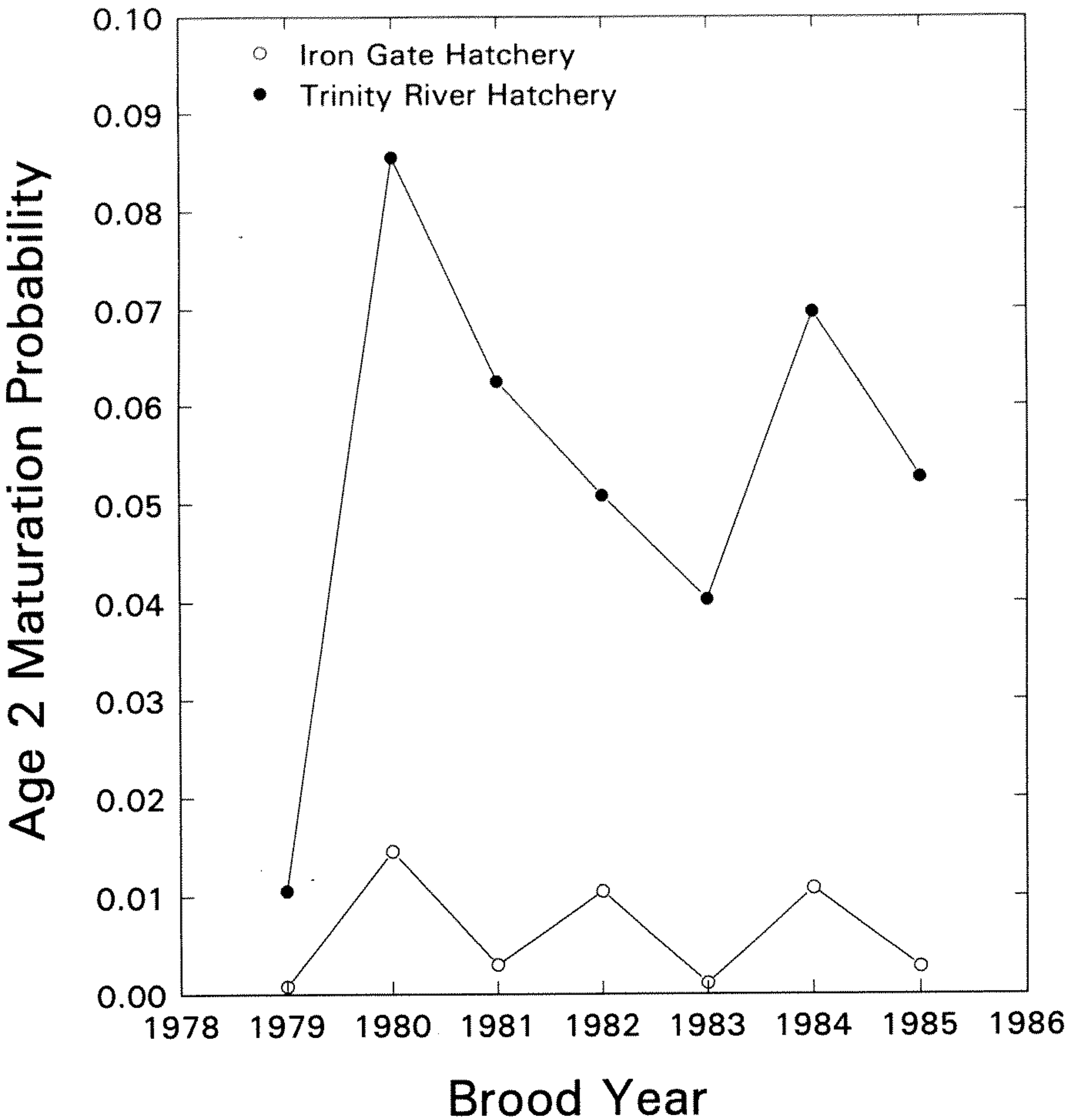

Figure 4. Estimated age 2 maturation probabilities for fall chinook salmon released as yearlings from IGH and TRH, 1978 - 1985 brood years.

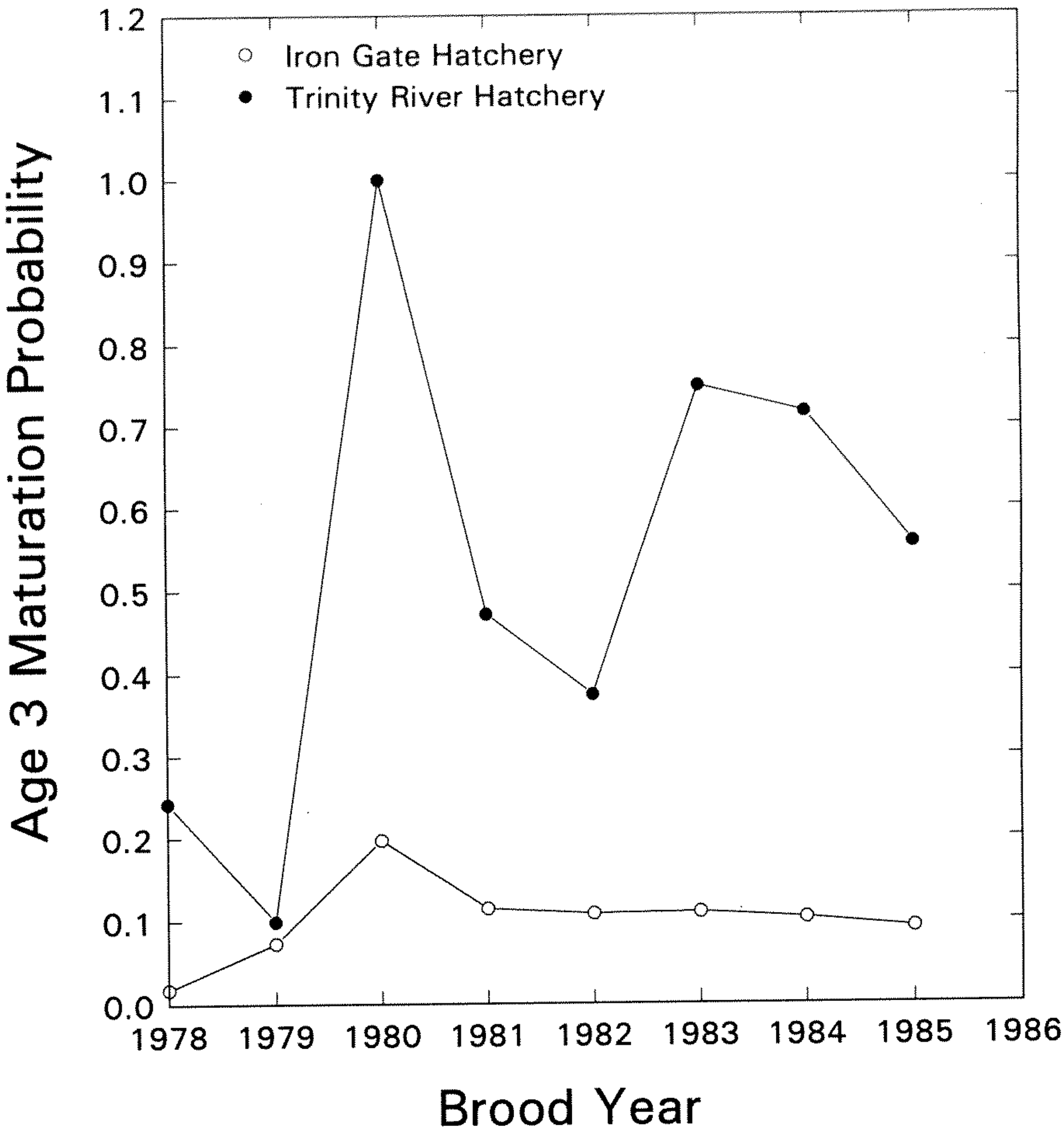

Figure 5. Estimated age 3 maturation probabilities for fall chinook salmon released as yearlings from IGH and TRH, 1978 - 1985 brood years.

DISCUSSION

We are extremely encouraged by the performance of our estimation methods based on estimated catches and escapements for CWT releases of yearling fall chinook salmon from IGH and TRH. For all practical purposes, recovery data and related estimates for TRH and IGH CWT releases are nearly independent of one another. Recovery probabilities in ocean fishery samples are so small for individual CWT groups that estimated catches of IGH and TRH groups are effectively independent of one another. In freshwater, estimates of freshwater catch of different groups must clearly be correlated with one another because CWT appearance rates in river net and sport fisheries are relatively high. Nevertheless, freshwater catches only constitute a part of the total freshwater escapement. Hatchery returns to IGH and TRH are clearly independent of one another and produce enumerations rather than estimates. Finally, methods for estimating stray escapement of TRH and IGH fish are very different and rely on nearly independent data sets. Thus, the striking agreement in the interannual pattern of estimated survival rates to age two (Figure 1) and in estimated (conditional) ocean survival rates (Figure 2) argues strongly that our methods have merit and that they produce meaningful estimates of life history and fishery parameters.

We emphasize that the methods that we have developed are limited in application to CWT recovery data sets for which it is possible to generate a "full accounting" of all recoveries, including estimates of total freshwater escapement at age. Hankin (1990), in his applications of single CWT group cohort analysis methods, found very few such data sets for California or Oregon stocks of chinook salmon. The extensive freshwater sampling programs carried out in the Klamath River system by the U.S. Fish and Wildlife Service, California Fish and Game, the U.S. Forest Service, and the Hoopa Valley Tribe probably produce the very best estimates of total freshwater escapement for any stock of fall chinook salmon from California, Oregon or Washington. Our methods also require that CWT releases are carried out on a continuous basis and that release group sizes are large. In this respect also, CWT recovery data sets for Klamath River fall chinook salmon are outstanding when compared to those for other stocks of chinook salmon. For every brood year since 1977, California Fish and Game has made major on-site (i.e. at hatchery) CWT releases of fingerlings (during June) and yearlings (during October/November) at both IGH and TRH. Release group sizes have generally been of a desirably large size: 150,000 - 200,000 for fingerlings, and about 100,000 for yearlings. California Fish and Game must be applauded for these large CWT release group sizes and for the continuity of its tagging program, both of which appear unrivaled in the Pacific Northwest.

Biological Implications of Results

Estimated survival rates from release to age 2 and ocean survival rates for older aged Klamath River salmon appear to relate meaningfully to the unusual El Nino event of 1982/83. We have made no formal studies of ocean environmental indicators in this project, but our informal communications with knowledgeable fishery scientists indicate that the substantial El Nino event produced unusually warm surface water temperatures and/or unusually high sea levels beginning in October of 1982 and lasting roughly through August of 1983. By October of 1983, these indicators of unusual ocean environment were "back to normal" (P. Lawson, pers. comm.). Physical condition of south-migrating (Nicholas and Hankin 1988) chinook salmon was poor in the ocean during the summer of 1983 and condition and size at age were also poor among hatchery returns that same year (Johnson 1984). Johnson argued that adult mortality increased during 1983, but his conclusion rested on unexpectedly low returns of south-migrating stocks to coastal rivers. This conclusion is unfortunately confounded by (unknown) possible reductions in age-specific maturation probabilities that might have resulted due to reduced size at age. Size at age has been shown to have a strong and positive influence on maturation (Hankin 1990).

Estimated survival rates from release to age 2 were exceptionally low for 1981 brood year yearling fall chinook releases from both IGH and TRH. These fish were released in October/November of 1982 and would have been immediately exposed to the developing unusual ocean climate during the 1982/83 El Nino event. Similarly, the estimated ocean survival rates for IGH and TRH fall chinook salmon from fall 1982 through spring 1983 were also unusually low, again coinciding with the "peak" of the El Nino event. In contrast, ocean survival rates were extremely good during the following fall/spring periods (1983/84 and 1984/85) for both stocks of chinook salmon, and the survival rate for the 1983 brood year releases (released in fall of 1984) was also exceptionally good. Thus, estimated survival rates from release to age 2 and ocean survival rates of older aged fish appear consistent with the presumed but undocumented impact of the 1982/83 El Nino event on ocean survival rates of chinook salmon.

Our statistical conclusion that "Model 3" was most appropriate for IGH yearling releases of fall chinook salmon is a conclusion that appears reasonable on biological grounds. This model assumes that age 4 maturation probabilities do not vary with brood year, but annual ocean survival rates are allowed to vary between years. First, estimates of age 4 maturation probabilities for the early-maturing stocks of chinook salmon reared at IGH and TRH are generally in excess of 90%, regardless of release type (Hankin 1990). Thus, any minor variation in age 4 maturation probabilities (which no doubt takes place) can be ignored with relative safety. Second, anecdotal evidence such as that presented above strongly suggests that ocean survival rates and survival rates from release to age 2 must have been substantially affected by the 1982/83 El Nino event that cut across virtually all of the data sets considered in this report. Thus, it was quite "natural" to anticipate that ocean survival rates varied over the period 1980 though 1990.

What we did not anticipate was the degree to which estimated ocean survival rates varied. Over an approximately ten year period, our estimates suggest that ocean survival rates of Klamath River fall chinook salmon have ranged from about 20% to 100%. Also, the 1982/83 fall/spring El Nino period was not the only year identified to produce low ocean survival rates; 1981/82 and 1985/86 fall/spring periods were equally poor. This substantial interannual variation in ocean survival rates and in age-specific maturation probabilities, especially among TRH fall chinook salmon, have important implications for pre-season prediction of the abundance of Klamath River fall chinook salmon, and for estimation of the Ricker α parameter for Klamath River fall chinook salmon based on cohort analysis reconstructions of recruited year-class strength. While we do not feel that it is appropriate to discuss these implications in detail in the context of this report, we do feel obligated to point out that the current method for pre-season estimation of abundance can be shown to invoke an implicit but untenable assumption that maturation probabilities of Klamath River fall chinook salmon do not vary between years.

Unsettled Statistical Issues

Although we feel relatively certain that the methods of analysis we have proposed and applied have substantial theoretical and practical merit, there are many important issues of application and development that remain unsettled or unexplored. Here we briefly mention some of these issues so that readers will not develop the false impression that the problem of estimating ocean survival rates of Pacific salmon has been "solved" by our research.

First, the relative advantages or disadvantages of the "four brood year" analysis as compared to the "eight brood year" analysis needs to be explored. In tag recovery models additional years of releases appear generally beneficial in that continually greater numbers of brood years are presumably at large at the beginning of successive recovery years. This might argue for analysis of the largest possible data sets. For chinook salmon, however, the maximum number of brood years that can be represented in any given recovery year is four for an early-maturing fall chinook stock. (Note that this maximum would be five brood years for a mid- or late-maturing stock for which many fish do not mature until age 6.) Although the "eight brood year" analysis can be extended to include an indefinite number of successive brood years of release, it is not clear that there is any benefit to this practice.

Related to the above issue of number of brood years is the issue of replication. Based on a comparison of the performance of our estimation methods between four brood year groups of TRH and IGH yearling releases of fall chinook salmon, replication appears to be advantageous. Analysis of (replicated) IGH groups resulted in a clear signal that Model 3 was appropriate, whereas this signal was not clear for the (unreplicated) TRH groups. This contrast in performance may, however, reflect some factor other than replication, such as differences in reliability of fresh-water escapement estimates between IGH and TRH groups. Our intuition suggests that replication is indeed highly desirable, however, and we therefore provisionally recommend that CWT releases of 100,000 - 150,000 yearlings that now receive a single identifying code instead be released as two "true replicate" groups of 50,000 - 75,000 fish, each with a different tag code. It may also prove possible to modify our methods of inclusion of "replicates" groups so that "partial replicates" could be included. For these partial replicates, differences in hatchery rearing and/or release practices might substantially alter survival rates from release until age 2, but would otherwise not be expected to have substantial effects on life history or fishery parameter values. The most obvious example of this kind of partial replication would be CWT groups which differ only in their location of release (e.g. many TRH off-site release groups). In principle, inclusion of recovery data for each such partial replicate group would increase the number of observations by 8 while increasing the number of parameters to estimate by just one - an additional survival rate from release to age 2 for the relevant brood year.

Although we have examined five alternative models (Models 1-5), there must be a great many more possible models, some of which may be as plausible as those that we have selected to develop thus far. In particular, alternative models should be explored to further address our preliminary conclusion that there is no evidence of differential ocean survival rates between age 2 and older chinook salmon. This conclusion may be correct but it may instead reflect our assumption that age two ocean survival rates are equal to survival rates of older fish raised to some constant power. Instead, survival rates of age 2 fish could be some simple fraction, γ, of survival rates for older fish: $S_{i2} = \gamma \cdot S_i$. Related to this issue of alternative models is the question of how to compare between alternative models when one model is not a simple reduction of a larger parameter model, but is instead of a different quality or structure. Also, it would be desirable to develop some measure of "goodness of fit" with which to judge whether *any* model provided an acceptable match with observed recovery data. Our current estimation methods allow only comparison among alternative models.

Although there is a theoretical basis for the methods we have used to attach errors of estimation to parameters estimated using our methods, there is no doubt substantial room for additional theoretical work in this problem area. Calculated errors of estimation presented in Appendix Tables C1 - C6 and discussed at various points in the text appear generally reasonable to us. We are concerned, however, that errors of estimation appear to be correlated with the magnitude of estimated ocean survival rates. This may or may not be generally true and there may or may not be a good reason for it.

Finally, we wish once more to emphasize the critical importance of those assumptions that we have made regarding relations among age-specific exploitation rates within recovery years. Although we believe that these assumptions are quite reasonable, they may in some cases be violated. For example, age 3 exploitation rates may depend not only on age 4 exploitation rates during the same recovery year, but also on size of age 3 fish (see Hankin 1990, Figure 1) and perhaps on the mixture of sport and commercial landings of Klamath salmon during that same year. In our further research and development of our proposed estimation methods we hope to address this issue and many of the other unsettled issues raised above.

PART II

MODEL SPECIFICATION

In our earlier research (Hankin and Mohr 1990, Appendix 1) we demonstrated the equivalence of two different methods of simulating the recovery data for a single CWT group of chinook salmon: (1) a series of conditionally binomial events (the *binomial chain* representation), and (2) a single multinomial process. In development of the estimation schemes presented in this report, we have instead elected to view the eight individual recovery "cells" for each CWT group as reflecting independent Poisson variables. A set of independent Poisson variables closely approximates a multinomial variable when the cell probabilities are small (Johnson and Kotz 1969), in the same manner that a single Poisson variable closely approximates a binomial variable for small p. Viewing the recovery data as a set of Poisson variables has substantial advantages in that certain key results from the theory of *generalized linear models* (McCullagh and Nelder 1989, Cormack 1989) can be applied.

If the independent Poisson model is adopted, then the expected value of the recoveries in "cell i" can be expressed as Np_i, where N is the CWT release group size, and p_i is the probability of entry into cell i (Cormack 1989). The probability, p_i, in turn depends on model parameters and the particular alternative model that is examined. Model parameters for our alternative models, along with their assumptions, are listed in Table 2 of Part I of this report. Expected values of catches and escapements of individual CWT groups at age directly follow Hankin and Healey (1986), with minor modifications due to model structure.

FITTING ALTERNATIVE MODELS

We used BMDP/386 (1991), program **3R** (Nonlinear Regression), to fit our alternative models. For members of the exponential family of probability distributions (including the Poisson), Green (1984) showed that the method of *iteratively reweighted least-squares* will produce the maximum likelihood estimates of model parameters. When observations are viewed as independent Poisson random variables, then the appropriate *weights* for observations are $1/f$, where f denotes the *expected value* of an observation based on the current iterations' estimates of model parameters. Thus, in our BMDP program code (Appendices A II and B II) we have specified **WT = 1/F**. Constraints that we imposed on model parameters were discussed in Part I. Initial guesses prove to be relatively unimportant for the BMDP algorithms, and derivatives do not need to be supplied by the user.

We based our comparisons among alternative models on the *total deviances* of each fitted model, scaled by the appropriate degrees of freedom. McCullagh and Nelder (1989) show that the deviance for the *i*th observation (assumed to reflect an independent Poisson random variable) is of the form:

$$D_i = 2[y_i ln(y_i/\hat{y}_i) - (y_i - \hat{y}_i)] \text{ for } y_i > 0 \text{ , or}$$

$$D_i = 2\hat{y}_i \text{ for } y_i = 0.$$

In the above expressions, the $\hat{y}_i$ indicate predicted observations based on estimated model parameters, whereas y_i indicate the actual observations (the estimated catches and escapements at age for each CWT group). The *total deviance* for a given set of observations and assumed model is simply the sum of all individual observation deviances.

For a true simple Poisson process, the expected value of the deviance (over all possible sample observations) is one so that the expected value of the total deviance for *n* observations assumed to be independent Poisson would be *n-p*. When a fitted "full model" results in a deviance substantially larger than this expectation, this phenomenon is termed *overdispersion* (see McCullagh and Nelder 1989). In this case, we define a quantity ϕ which is analogous to the residual error, scaled by degrees of freedom, in a fitted linear regression model. For our research, we defined Model 4 as our "full model"; this model thus becomes the basis for estimating ϕ. Letting *D* equal the total deviance of a fitted model at the maximum likelihood solutions for model parameters:

$$\hat{\phi} = D/(n - m) \quad ,$$

where *m* denotes number of parameters for the "full model" and *n* denotes the number of observations for the fitted data set.

The differences between deviances can now be used to compare among alternative models. As illustration, let D_4 and D_3 denote the deviances for the full model, Model 4, and the reduced model, Model 3, for some CWT data set. Then,

$$(D_3 - D_4)/\hat{\phi}(30 - 27)$$

is approximately distributed as *F* with degrees of freedom 3 and (*n* - 30), where 3 is the difference in the number of parameters (30 - 27) between Model 3 and Model 4 for the four brood year analysis for some CWT recovery data set. If this F statistic is non-significant, then one would conclude that Model 3 is no less acceptable a model than Model 4, and one would proceed to compare some further reduced model, for example Model 1, against Model 3. An analogous statistic would be used for the latter comparison and the same estimate of ϕ would appear in the denominator.

Finally, once the "appropriate" model is selected, a final estimate of ϕ should be calculated as the total deviance for this appropriate model divided by its corresponding degrees of freedom $(n - m)$. BMDP allows easy calculation of deviances through specification of a "loss function" as illustrated in the computer programs listed in Appendices A and B.

Errors of estimation of estimated model parameters are routinely calculated by BMDP using the variance - covariance matrix at the final iteration at which time the maximum likelihood solutions for model parameter estimates have been achieved. As listed in the Appendices, we specified **"MEAN SQUARE = 1.0"** in our computer programs, analogous to an assumption that each observation was indeed the outcome of a simple Poisson process or to an assumption that the residual mean square (σ^2) equals one in a regression context. We found that our estimates of ϕ were much greater than one, however, indicating substantial overdispersion. Therefore, all BMDP estimates of the standard errors of estimated model parameters were scaled up by the square root of the final estimate of ϕ based on the appropriate model (Model 3).

LITERATURE CITED

BMDP/386. 1991. BMDP statistical software, inc. 1440 Sepulveda Blvd., Suite 316, Los Angeles CA 90025.

Brownie, C, D.R. Anderson, K.P. Burnham, and D.S. Robson. 1978. Statistical inference from band recovery data - a handbook. U.S.D.I., Fish & Wildlife Service, Resource Publication NO. 131, Washington, D.C. 212 pp.

Brownie, C, D.R. Anderson, K.P. Burnham, and D.S. Robson. 1985. Statistical inference from band recovery data - a handbook. Second edition. U.S.D.I., Fish & Wildlife Service, Resource Publication NO. 156, Washington, D.C. 305 pp.

Cleaver, F.C. 1969. Effects of ocean fishing on the 1961-brood fall chinook salmon from Columbia River hatcheries. Fish. Comm. Or. Res. Rep. 1: 1-75.

Cormack, R.M. 1989. Log-linear models for capture-recapture. Biometrics 45: 395-413

Cramer, S.P. 1990. Contribution of Sacramento basin hatcheries to ocean catch and river escapement of fall chinook salmon. Contract report prepared for Cal. Dept. Water Resources, S.P. Cramer and Assoc., Corvallis, OR. 113 pp. + Appendixes.

Green, P.J. 1984. Iteratively reweighted least squares for maximum likelihood estimation, and some robust and resistant alternatives. J. Royal Stat. Soc. 46(2): 149-192.

Hankin, D.G. 1985. Analyses of recovery data for marked chinook salmon released from Iron Gate and Trinity River hatcheries, and their implications for management of wild and hatchery chinook stocks in the Klamath River system. Contract report for Bureau of Indian Affairs, Northern California Agency, Hoopa, CA. 117 pp.

Hankin, D.G. 1990. Effects of month of release of hatchery-reared chinook salmon on size at age, maturation schedule, and fishery contribution. Information Rep. No. 90-4, Oregon Dept. of Fish & Wildlife, Portland, OR. 37 pp.

Hankin, D.G., and N. Diamond. 1984. A data compilation of marked releases and recoveries of fall chinook salmon from the Klamath River system: 1977 - 1983. Contract report for Bureau of Indian Affairs, Northern California Agency, Hoopa, CA. 102 pp.

Hankin, D.G., and M.C. Healey. 1986. Dependence of exploitation rates for maximum yield and stock collapse on age and sex structure of chinook salmon stocks. Can. J. Fish. Aquat. Sci. 43: 1746-1759.

Hankin, D.G., and M.S. Mohr. 1990. Final Report: Determination of levels of coded-wire tagging needed to support time/area harvest management. Report prepared for U.S. Fish & Wildlife Service, Weaverville, CA office via California Cooperative Fishery Unit Research Work Order No. 22. 60 pp.

Johnson, S. 1984. The effects of the 1983 El Nino on Oregon's coho and chinook salmon. Information Rep. No. 84-8, Oregon Dept. of Fish & Wildlife, Portland, OR. 37 pp.

Johnson, N.L., and S. Kotz. 1969. Discrete distributions. Houghton-Mifflin, Boston. 328 pp.

KRTAT. 1986. Recommended spawning escapement policy for Klamath River fall-run chinook.

KRTAT. 1990. Progress report: Cohort analysis of Klamath River fall chinook salmon of the 1979 through 1984 broods.

McCullagh, P., and J.A. Nelder. Generalized linear models, second edition. Chapman and Hall, New York. 511 pp.

Nicholas, J.W., and D.G. Hankin. 1988. Chinook salmon populations in Oregon coastal river basins: description of life histories and assessment of recent trends in run strengths. Information Rep. No. 88-1, Oregon Dept. of Fish & Wildlife, Portland, OR. 359 pp.

Parker, R.R., and W. Kirkness. 1956. King salmon in the ocean troll fishery of southeastern Alaska. Alaska Dep. Fish. Res. Rep. 1: 1-64.

Ricker, W.E. 1975. Computation and interpretation of the biological statistics of fish populations. Bulletin 191. Fish. Res. Board Can. 382 pp.

___________. 1976. Review of the rate of growth and mortality of Pacific salmon and non-catch mortality caused by fishing. J. Fish. Res. Board Can. 33: 1483-1524.

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Appendix A. Sample BMDP data file and BMDP program code for data analysis based on four successive groups, and with parameterizations of m = 23, 24, 27 and 30, respectively.

I. Data file - **I78ALLY.DAT**. Iron Gate Hatchery releases of yearling fall chinook salmon, 1978 through 1981 brood years.

```
Y12     0  191071
Y13  2508  191071
Y14  1778  191071
Y15     6  191071
E12    19  191071
E13   415  191071
E14  1122  191071
E15    17  191071
Y22     5   91000
Y23  1030   91000
Y24   744   91000
Y25     5   91000
E22    29   91000
E23   272   91000
E24   159   91000
E25     4   91000
Y32    20   87450
Y33   166   87450
Y34   400   87450
Y35     7   87450
E32    67   87450
E33   202   87450
E34   368   87450
E35    49   87450
Y42     0   65385
Y43    72   65385
Y44   106   65385
Y45     0   65385
E42     2   65385
E43    57   65385
E44   200   65385
E45     1   65385
Y42     2   25586
Y43    26   25586
Y44    86   25586
Y45     0   25586
E42     1   25586
E43    21   25586
E44   168   25586
E45     4   25586
Y42     2   30781
Y43    21   30781
Y44    47   30781
Y45     0   30781
E42     0   30781
E43    21   30781
E44   131   30781
E45     0   30781
```

II. BMDP program code.

```
/ INPUT                 FILE = 'I78ALLY.DAT'.
                        VARIABLES = 3.
                        FORMAT IS FREE.
                        CASES = 48.

/ VARIABLES             NAMES = CODE, CATCHES, RELEASES.
                        LABELS= CODE.
```

```
/ REGRESS    DEPENDENT = CATCHES.
             PARAM = 23.
             ITER = 75.
             MEANSQUARE = 1.0.
             WEIGHT = WT.
             LOSS.
             TOLERANCE = .001.

/ TRANSFORM WT = 1.0.

/ PARAM

  NAME =       P1, S20, S30, S40, P2,
               s13, s22, s23, s32, s33, s42, s43, s44,
               P3, r2, r3, S,
               u13, u14, u24, u34, u44, u45.

  INITIAL = .001, .024, .006, .022, .0001,
            .3739, .0029, .2782, .028, .2854, .0126, .1750, .98,
            .001, 2, 1.5, .5,
            .4373, .3824, .2700, .5617, .5556, .5263.

   MINIMUM = .000001, .00001, .00001, .00001, .00001,
             .00001, .00001, .00001, .00001, .00001, .00001, .00001, .00001,
             .00001, .00001, .00001, .00001,
             .00001, .00001, .00001, .00001, .00001, .00001.

   MAXIMUM =  1, .4, .4, .4, 1,
              1, 1, 1, 1, 1, 1, 1, 1,
              1, 10, 10, 1,
              1, 1, 1, 1, 1, 1.

/ FUNCTION  u22 = u13**r2.
            u23 = u14**r3.
            u32 = u23**r2.
            u33 = u24**r3.
            u42 = u33**r2.
            u43 = u34**r3.
            u15 = u24.
            u25 = u34.
            u35 = u44.
            s14 = s44.
            s24 = s44.
            s34 = s44.

            A13 = P3*S*RELEASES.
            A14 = A13*(1-u13)*(1-s13)*S.
            A15 = A14*(1-u14)*(1-s14)*S.

            A22 = S20*RELEASES.
            A23 = A22*(1-u22)*(1-s22)*S.
            A24 = A23*(1-u23)*(1-s23)*S.
            A25 = A24*(1-u24)*(1-s24)*S.

            A32 = S30*RELEASES.
            A33 = A32*(1-u32)*(1-s32)*S.
            A34 = A33*(1-u33)*(1-s33)*S.
            A35 = A34*(1-u34)*(1-s34)*S.

            A42 = S40*RELEASES.
            A43 = A42*(1-u42)*(1-s42)*S.
            A44 = A43*(1-u43)*(1-s43)*S.
            A45 = A44*(1-u44)*(1-s44)*S.

            IF (CODE == CHAR(Y12)) THEN F = P1*RELEASES.
            IF (CODE == CHAR(Y13)) THEN F = u13*A13.
            IF (CODE == CHAR(Y14)) THEN F = u14*A14.
            IF (CODE == CHAR(Y15)) THEN F = u15*A15.
            IF (CODE == CHAR(E12)) THEN F = P2*RELEASES.
            IF (CODE == CHAR(E13)) THEN F = s13*(1-u13)*A13.
            IF (CODE == CHAR(E14)) THEN F = s14*(1-u14)*A14.
            IF (CODE == CHAR(E15)) THEN F = (1-u15)*A15.
```

```
            IF (CODE == CHAR(Y22)) THEN F = u22*A22.
            IF (CODE == CHAR(Y23)) THEN F = u23*A23.
            IF (CODE == CHAR(Y24)) THEN F = u24*A24.
            IF (CODE == CHAR(Y25)) THEN F = u25*A25.
            IF (CODE == CHAR(E22)) THEN F = s22*(1-u22)*A22.
            IF (CODE == CHAR(E23)) THEN F = s23*(1-u23)*A23.
            IF (CODE == CHAR(E24)) THEN F = s24*(1-u24)*A24.
            IF (CODE == CHAR(E25)) THEN F = (1-u25)*A25.

            IF (CODE == CHAR(Y32)) THEN F = u32*A32.
            IF (CODE == CHAR(Y33)) THEN F = u33*A33.
            IF (CODE == CHAR(Y34)) THEN F = u34*A34.
            IF (CODE == CHAR(Y35)) THEN F = u35*A35.
            IF (CODE == CHAR(E32)) THEN F = s32*(1-u32)*A32.
            IF (CODE == CHAR(E33)) THEN F = s33*(1-u33)*A33.
            IF (CODE == CHAR(E34)) THEN F = s34*(1-u34)*A34.
            IF (CODE == CHAR(E35)) THEN F = (1-u35)*A35.

            IF (CODE == CHAR(Y42)) THEN F = u42*A42.
            IF (CODE == CHAR(Y43)) THEN F = u43*A43.
            IF (CODE == CHAR(Y44)) THEN F = u44*A44.
            IF (CODE == CHAR(Y45)) THEN F = u45*A45.
            IF (CODE == CHAR(E42)) THEN F = s42*(1-u42)*A42.
            IF (CODE == CHAR(E43)) THEN F = s43*(1-u43)*A43.
            IF (CODE == CHAR(E44)) THEN F = s44*(1-u44)*A44.
            IF (CODE == CHAR(E45)) THEN F = (1-u45)*A45.

            WT = 1/F.

  IF (CATCHES = 0) THEN (DEV = 2*F).
  IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) >= .001)) THEN
       (DEV = 2*((CATCHES*(LN(CATCHES/F)))-(CATCHES-F))).
  IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) < .001)) THEN
       (DEV = (2-(CATCHES/F))*(((F-CATCHES)**2)/F)).
       XLOSS = DEV.

/ END

/ INPUT                 FILE = 'I78ALLY.DAT'.
                        VARIABLES = 3.
                        FORMAT IS FREE.
                        CASES = 48.

/ VARIABLES             NAMES = CODE, CATCHES, RELEASES.
                        LABELS= CODE.

/ REGRESS    DEPENDENT = CATCHES.
             PARAM = 24.
             ITER = 75.
             MEANSQUARE = 1.0.
             WEIGHT = WT.
             LOSS.
             TOLERANCE = .001.

/ TRANSFORM WT = 1.0.

/ PARAM

  NAME =      P1, S20, S30, S40, P2,
              s13, s22, s23, s32, s33, s42, s43, s44,
              P3, r2, r3, S2, S3,
              u13, u14, u24, u34, u44, u45.

  INITIAL = .001, .024, .006, .022, .0001,
            .3739, .0029, .2782, .028, .2854, .0126, .1750, .98,
            .001, 2, 1.5, .5, .5,
            .4373, .3824, .2700, .5617, .5556, .5263.

   MINIMUM = .000001, .00001, .00001, .00001, .00001,
             .00001, .00001, .00001, .00001, .00001, .00001, .00001, .00001,
             .00001, .00001, .00001, .00001, .00001,
             .00001, .00001, .00001, .00001, .00001, .00001.
```

```
MAXIMUM =  1, .4, .4, .4, 1,
           1, 1, 1, 1, 1, 1, 1, 1,
           1, 10, 10, 1, 1,
           1, 1, 1, 1, 1, 1.

/ FUNCTION  u22 = u13**r2.
            u23 = u14**r3.
            u32 = u23**r2.

            u33 = u24**r3.
            u42 = u33**r2.
            u43 = u34**r3.
            u15 = u24.
            u25 = u34.
            u35 = u44.
            s14 = s44.
            s24 = s44.
            s34 = s44.

            A13 = P3*S2*RELEASES.
            A14 = A13*(1-u13)*(1-s13)*S3.
            A15 = A14*(1-u14)*(1-s14)*S3.

            A22 = S20*RELEASES.
            A23 = A22*(1-u22)*(1-s22)*S2.
            A24 = A23*(1-u23)*(1-s23)*S3.
            A25 = A24*(1-u24)*(1-s24)*S3.

            A32 = S30*RELEASES.
            A33 = A32*(1-u32)*(1-s32)*S2.
            A34 = A33*(1-u33)*(1-s33)*S3.
            A35 = A34*(1-u34)*(1-s34)*S3.

            A42 = S40*RELEASES.
            A43 = A42*(1-u42)*(1-s42)*S2.
            A44 = A43*(1-u43)*(1-s43)*S3.
            A45 = A44*(1-u44)*(1-s44)*S3.

            IF (CODE == CHAR(Y12)) THEN F = P1*RELEASES.
            IF (CODE == CHAR(Y13)) THEN F = u13*A13.
            IF (CODE == CHAR(Y14)) THEN F = u14*A14.
            IF (CODE == CHAR(Y15)) THEN F = u15*A15.
            IF (CODE == CHAR(E12)) THEN F = P2*RELEASES.
            IF (CODE == CHAR(E13)) THEN F = s13*(1-u13)*A13.
            IF (CODE == CHAR(E14)) THEN F = s14*(1-u14)*A14.
            IF (CODE == CHAR(E15)) THEN F = (1-u15)*A15.

            IF (CODE == CHAR(Y22)) THEN F = u22*A22.
            IF (CODE == CHAR(Y23)) THEN F = u23*A23.
            IF (CODE == CHAR(Y24)) THEN F = u24*A24.
            IF (CODE == CHAR(Y25)) THEN F = u25*A25.
            IF (CODE == CHAR(E22)) THEN F = s22*(1-u22)*A22.
            IF (CODE == CHAR(E23)) THEN F = s23*(1-u23)*A23.
            IF (CODE == CHAR(E24)) THEN F = s24*(1-u24)*A24.
            IF (CODE == CHAR(E25)) THEN F = (1-u25)*A25.

            IF (CODE == CHAR(Y32)) THEN F = u32*A32.
            IF (CODE == CHAR(Y33)) THEN F = u33*A33.
            IF (CODE == CHAR(Y34)) THEN F = u34*A34.
            IF (CODE == CHAR(Y35)) THEN F = u35*A35.
            IF (CODE == CHAR(E32)) THEN F = s32*(1-u32)*A32.
            IF (CODE == CHAR(E33)) THEN F = s33*(1-u33)*A33.
            IF (CODE == CHAR(E34)) THEN F = s34*(1-u34)*A34.
            IF (CODE == CHAR(E35)) THEN F = (1-u35)*A35.

            IF (CODE == CHAR(Y42)) THEN F = u42*A42.
            IF (CODE == CHAR(Y43)) THEN F = u43*A43.
            IF (CODE == CHAR(Y44)) THEN F = u44*A44.
            IF (CODE == CHAR(Y45)) THEN F = u45*A45.
            IF (CODE == CHAR(E42)) THEN F = s42*(1-u42)*A42.
            IF (CODE == CHAR(E43)) THEN F = s43*(1-u43)*A43.
            IF (CODE == CHAR(E44)) THEN F = s44*(1-u44)*A44.
            IF (CODE == CHAR(E45)) THEN F = (1-u45)*A45.
```

```
            WT = 1/F.

 IF (CATCHES = 0) THEN (DEV = 2*F).
 IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) >= .001)) THEN
      (DEV = 2*((CATCHES*(LN(CATCHES/F)))-(CATCHES-F))).
 IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) < .001)) THEN
      (DEV = (2-(CATCHES/F))*(((F-CATCHES)**2)/F)).
      XLOSS = DEV.

/ END

/ INPUT                   FILE = 'I78ALLY.DAT'.
                          VARIABLES = 3.
                          FORMAT IS FREE.
                          CASES = 48.

/ VARIABLES               NAMES = CODE, CATCHES, RELEASES.
                          LABELS= CODE.

/ REGRESS    DEPENDENT = CATCHES.
             PARAM = 27.
             ITER = 75.
             MEANSQUARE = 1.0.
             WEIGHT = WT.
             LOSS.
             TOLERANCE = .001.

/ TRANSFORM WT = 1.0.

/ PARAM

  NAME =      P1, S20, S30, S40, P2,
              s13, s22, s23, s32, s33, s42, s43, s44,
              P3, r2, r3, S3, S4, S5, S6, S7,
              u13, u14, u24, u34, u44, u45.

  INITIAL = .001, .024, .006, .022, .0001,
            .3739, .0029, .2782, .028, .2854, .0126, .1750, .98,
            .001, 2, 1.5, .5, .5, .5, .5, .5,
            .4373, .3824, .2700, .5617, .5556, .5263.

   MINIMUM = .000001, .00001, .00001, .00001, .00001,
             .00001, .00001, .00001, .00001, .00001, .00001, .00001, .00001,
             .00001, .00001, .00001, .00001, .00001, .00001, .00001, .00001,
             .00001, .00001, .00001, .00001, .00001, .00001.

   MAXIMUM =  1, .4, .4, .4, 1,
              1, 1, 1, 1, 1, 1, 1, 1,
              1, 10, 10, 1, 1, 1, 1, 1,
              1, 1, 1, 1, 1, 1.

/ FUNCTION  u22 = u13**r2.
            u23 = u14**r3.
            u32 = u23**r2.
            u33 = u24**r3.
            u42 = u33**r2.
            u43 = u34**r3.
            u15 = u24.
            u25 = u34.
            u35 = u44.
            s14 = s44.
            s24 = s44.
            s34 = s44.

            A13 = P3*RELEASES.
            A14 = A13*(1-u13)*(1-s13)*S3.
            A15 = A14*(1-u14)*(1-s14)*S4.

            A22 = S20*RELEASES.
            A23 = A22*(1-u22)*(1-s22)*S3.
            A24 = A23*(1-u23)*(1-s23)*S4.
            A25 = A24*(1-u24)*(1-s24)*S5.
```

```
          A32 = S30*RELEASES.
          A33 = A32*(1-u32)*(1-s32)*S4.
          A34 = A33*(1-u33)*(1-s33)*S5.
          A35 = A34*(1-u34)*(1-s34)*S6.

          A42 = S40*RELEASES.
          A43 = A42*(1-u42)*(1-s42)*S5.
          A44 = A43*(1-u43)*(1-s43)*S6.
          A45 = A44*(1-u44)*(1-s44)*S7.

          IF (CODE == CHAR(Y12)) THEN F = P1*RELEASES.
          IF (CODE == CHAR(Y13)) THEN F = u13*A13.
          IF (CODE == CHAR(Y14)) THEN F = u14*A14.
          IF (CODE == CHAR(Y15)) THEN F = u15*A15.
          IF (CODE == CHAR(E12)) THEN F = P2*RELEASES.
          IF (CODE == CHAR(E13)) THEN F = s13*(1-u13)*A13.
          IF (CODE == CHAR(E14)) THEN F = s14*(1-u14)*A14.
          IF (CODE == CHAR(E15)) THEN F = (1-u15)*A15.

          IF (CODE == CHAR(Y22)) THEN F = u22*A22.
          IF (CODE == CHAR(Y23)) THEN F = u23*A23.
          IF (CODE == CHAR(Y24)) THEN F = u24*A24.
          IF (CODE == CHAR(Y25)) THEN F = u25*A25.
          IF (CODE == CHAR(E22)) THEN F = s22*(1-u22)*A22.
          IF (CODE == CHAR(E23)) THEN F = s23*(1-u23)*A23.
          IF (CODE == CHAR(E24)) THEN F = s24*(1-u24)*A24.
          IF (CODE == CHAR(E25)) THEN F = (1-u25)*A25.

          IF (CODE == CHAR(Y32)) THEN F = u32*A32.
          IF (CODE == CHAR(Y33)) THEN F = u33*A33.
          IF (CODE == CHAR(Y34)) THEN F = u34*A34.
          IF (CODE == CHAR(Y35)) THEN F = u35*A35.
          IF (CODE == CHAR(E32)) THEN F = s32*(1-u32)*A32.
          IF (CODE == CHAR(E33)) THEN F = s33*(1-u33)*A33.
          IF (CODE == CHAR(E34)) THEN F = s34*(1-u34)*A34.
          IF (CODE == CHAR(E35)) THEN F = (1-u35)*A35.

          IF (CODE == CHAR(Y42)) THEN F = u42*A42.
          IF (CODE == CHAR(Y43)) THEN F = u43*A43.
          IF (CODE == CHAR(Y44)) THEN F = u44*A44.
          IF (CODE == CHAR(Y45)) THEN F = u45*A45.
          IF (CODE == CHAR(E42)) THEN F = s42*(1-u42)*A42.
          IF (CODE == CHAR(E43)) THEN F = s43*(1-u43)*A43.
          IF (CODE == CHAR(E44)) THEN F = s44*(1-u44)*A44.
          IF (CODE == CHAR(E45)) THEN F = (1-u45)*A45.

          WT = 1/F.

 IF (CATCHES = 0) THEN (DEV = 2*F).
 IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) >= .001)) THEN
      (DEV = 2*((CATCHES*(LN(CATCHES/F)))-(CATCHES-F))).
 IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) < .001)) THEN
      (DEV = (2-(CATCHES/F))*(((F-CATCHES)**2)/F)).
      XLOSS = DEV.

/ END

/ INPUT                  FILE = 'I78ALLY.DAT'.
                         VARIABLES = 3.
                         FORMAT IS FREE.
                         CASES = 48.

/ VARIABLES              NAMES = CODE, CATCHES, RELEASES.
                         LABELS= CODE.

/ REGRESS    DEPENDENT = CATCHES.
             PARAM = 30.
             ITER = 75.
             MEANSQUARE = 1.0.
             WEIGHT = WT.
             LOSS.
             TOLERANCE = .001.
```

```
/ TRANSFORM WT = 1.0.

/ PARAM

  NAME =      P1, S20, S30, S40, P2,
              s13, s14, s22, s23, s24, s32, s33, s34, s42, s43, s44,
              P3, r2, r3, S3, S4, S5, S6, S7,
              u13, u14, u24, u34, u44, u45.

  INITIAL = .001, .024, .006, .022, .0001,
            .3739, .9, .0029, .2782, .9, .028, .2854, .9, .0126, .1750, .98,
            .0001, 2, 1.5, .5, .5, .5, .5, .5,
            .4373, .3824, .2700, .5617, .5556, .5263.


   MINIMUM = .000001, .00001, .00001, .00001, .00001,
         .00001, .00001,
         .00001, .00001, .00001, .00001, .00001, .00001.

   MAXIMUM =  1, .4, .4, .4, 1,
              1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
              1, 10, 10, 1, 1, 1, 1, 1,
              1, 1, 1, 1, 1, 1.

/ FUNCTION  u22 = u13**r2.
            u23 = u14**r3.
            u32 = u23**r2.
            u33 = u24**r3.
            u42 = u33**r2.
            u43 = u34**r3.
            u15 = u24.
            u25 = u34.
            u35 = u44.

            A13 = P3*RELEASES.
            A14 = A13*(1-u13)*(1-s13)*S3.
            A15 = A14*(1-u14)*(1-s14)*S4.

            A22 = S20*RELEASES.
            A23 = A22*(1-u22)*(1-s22)*S3.
            A24 = A23*(1-u23)*(1-s23)*S4.
            A25 = A24*(1-u24)*(1-s24)*S5.

            A32 = S30*RELEASES.
            A33 = A32*(1-u32)*(1-s32)*S4.
            A34 = A33*(1-u33)*(1-s33)*S5.
            A35 = A34*(1-u34)*(1-s34)*S6.

            A42 = S40*RELEASES.
            A43 = A42*(1-u42)*(1-s42)*S5.
            A44 = A43*(1-u43)*(1-s43)*S6.
            A45 = A44*(1-u44)*(1-s44)*S7.

            IF (CODE == CHAR(Y12)) THEN F = P1*RELEASES.
            IF (CODE == CHAR(Y13)) THEN F = u13*A13.
            IF (CODE == CHAR(Y14)) THEN F = u14*A14.
            IF (CODE == CHAR(Y15)) THEN F = u15*A15.
            IF (CODE == CHAR(E12)) THEN F = P2*RELEASES.
            IF (CODE == CHAR(E13)) THEN F = s13*(1-u13)*A13.
            IF (CODE == CHAR(E14)) THEN F = s14*(1-u14)*A14.
            IF (CODE == CHAR(E15)) THEN F = (1-u15)*A15.

            IF (CODE == CHAR(Y22)) THEN F = u22*A22.
            IF (CODE == CHAR(Y23)) THEN F = u23*A23.
            IF (CODE == CHAR(Y24)) THEN F = u24*A24.
            IF (CODE == CHAR(Y25)) THEN F = u25*A25.
            IF (CODE == CHAR(E22)) THEN F = s22*(1-u22)*A22.
            IF (CODE == CHAR(E23)) THEN F = s23*(1-u23)*A23.
            IF (CODE == CHAR(E24)) THEN F = s24*(1-u24)*A24.
            IF (CODE == CHAR(E25)) THEN F = (1-u25)*A25.
```

```
            IF (CODE == CHAR(Y32)) THEN F = u32*A32.
            IF (CODE == CHAR(Y33)) THEN F = u33*A33.
            IF (CODE == CHAR(Y34)) THEN F = u34*A34.
            IF (CODE == CHAR(Y35)) THEN F = u35*A35.
            IF (CODE == CHAR(E32)) THEN F = s32*(1-u32)*A32.
            IF (CODE == CHAR(E33)) THEN F = s33*(1-u33)*A33.
            IF (CODE == CHAR(E34)) THEN F = s34*(1-u34)*A34.
            IF (CODE == CHAR(E35)) THEN F = (1-u35)*A35.

            IF (CODE == CHAR(Y42)) THEN F = u42*A42.
            IF (CODE == CHAR(Y43)) THEN F = u43*A43.
            IF (CODE == CHAR(Y44)) THEN F = u44*A44.
            IF (CODE == CHAR(Y45)) THEN F = u45*A45.
            IF (CODE == CHAR(E42)) THEN F = s42*(1-u42)*A42.
            IF (CODE == CHAR(E43)) THEN F = s43*(1-u43)*A43.
            IF (CODE == CHAR(E44)) THEN F = s44*(1-u44)*A44.
            IF (CODE == CHAR(E45)) THEN F = (1-u45)*A45.

            WT = 1/F.

 IF (CATCHES = 0) THEN (DEV = 2*F).
 IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) >= .001)) THEN
      (DEV = 2*((CATCHES*(LN(CATCHES/F)))-(CATCHES-F))).
 IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) < .001)) THEN
      (DEV = (2-(CATCHES/F))*(((F-CATCHES)**2)/F)).
      XLOSS = DEV.

/ END
```

Appendix B. Sample BMDP data file and BMDP program code for data analysis based on eight successive groups, and with parameterizations of m = 39, 47 and 54, respectively. For the four group case listed as Appendix A, these parameterizations correspond to "m" = 23, 27, and 30, respectively.

I. Data file - **IGHALLY.DAT**. Iron Gate Hatchery releases of yearling fall chinook salmon, 1978 through 1985 brood years.

```
Y12     0  191071
Y13  2508  191071
Y14  1778  191071
Y15     6  191071
E12    19  191071
E13   415  191071
E14  1122  191071
E15    17  191071
Y22     5   91000
Y23  1030   91000
Y24   744   91000
Y25     5   91000
E22    29   91000
E23   272   91000
E24   159   91000
E25     4   91000
Y32    20   87450
Y33   166   87450
Y34   400   87450
Y35     7   87450
E32    67   87450
E33   202   87450
E34   368   87450
E35    49   87450
Y42     0   65385
Y43    72   65385
Y44   106   65385
Y45     0   65385
E42     2   65385
E43    57   65385
E44   200   65385
E45     1   65385
Y42     2   25586
Y43    26   25586
Y44    86   25586
Y45     0   25586
E42     1   25586
E43    21   25586
E44   168   25586
E45     4   25586
Y42     2   30781
Y43    21   30781
Y44    47   30781
Y45     0   30781
E42     0   30781
E43    21   30781
E44   131   30781
E45     0   30781
Y52     2   39127
Y53   472   39127
Y54   243   39127
Y55     5   39127
E52    53   39127
E53   470   39127
E54   229   39127
E55     0   39127
```

```
Y52      2   36997
Y53    461   36997
Y54    166   36997
Y55      0   36997
E52     85   36997
E53    372   36997
E54    257   36997
E55      1   36997
Y52      2   70171
Y53    633   70171
Y54    445   70171
Y55      2   70171
E52     26   70171
E53    645   70171
E54    381   70171
E55      1   70171
Y62      1   94738
Y63    666   94738
Y64   1474   94738
Y65     13   94738
E62     24   94738
E63    330   94738
E64   1203   94738
E65     20   94738
Y62      0   22599
Y63    118   22599
Y64    525   22599
Y65     12   22599
E62     15   22599
E63    190   22599
E64    308   22599
E65     12   22599
Y62      3   24830
Y63    263   24830
Y64    435   24830
Y65      6   24830
E62     27   24830
E63    306   24830
E64    305   24830
E65     13   24830
Y62      7   23766
Y63    218   23766
Y64    424   23766
Y65     16   23766
E62     10   23766
E63    100   23766
E64    361   23766
E65      8   23766
Y72      6   98500
Y73    975   98500
Y74   1149   98500
Y75     58   98500
E72     91   98500
E73    490   98500
E74    891   98500
E75     37   98500
Y82      2   95296
Y83    330   95296
Y84    969   95296
Y85     26   95296
E82     14   95296
E83    194   95296
E84    900   95296
E85      4   95296
```

II. BMDP Program code.

```
/ INPUT                 FILE = 'IGHALLY.DAT'.
                        VARIABLES = 3.
                        FORMAT IS FREE.
                        CASES = 120.
```

```
/ VARIABLES              NAMES = CODE, CATCHES, RELEASES.
                         LABELS= CODE.

/ REGRESS    DEPENDENT = CATCHES.
             PARAM = 39.
             ITER = 75.
             MEANSQUARE = 1.0.
             WEIGHT = WT.
             LOSS.
             TOLERANCE = .001.
/ TRANSFORM WT = 1.0.

/ PARAM

  NAME =      P1, S20, S30, S40, S50, S60, S70, S80, P2,
              s13, s22, s23, s32, s33, s42, s43,
              s52, s53, s62, s63, s72, s73, s82, s83, s84,
              P3, r2, r3, S,
              u13, u14, u24, u34, u44, u54, u64,
              u74, u84, u85.

  INITIAL = .0001, .02, .02, .02, .02, .02, .02, .02, .0001,
            .2, .05, .2, .05, .2, .05, .2,
            .05, .2, .05, .2, .05, .2, .05, .2, .9,
            .01, 2.5, 1.5, .5,
            .2, .4, .4, .4, .4, .4, .4,
            .4, .4, .4.

MINIMUM = .000001, .0001, .0001, .0001, .0001, .0001, .0001, .0001, .000001,
          .001, .0001, .001, .0001, .001, .0001, .001,
          .0001, .001, .0001, .001, .0001, .001, .0001, .01, .1,
          .00001, .00001, .00001, .00001,
          .01, .1, .1, .1, .1, .1, .1,
          .1, .1, .1.

MAXIMUM =  1, .4, .4, .4, .4, .4, .4, .4, 1,
           1, 1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1,
           1, 10, 10, 1,
           1, 1, 1, 1, 1, 1, 1,
           1, 1, 1.

/ FUNCTION  u22 = u13**r2.
            u23 = u14**r3.
            u32 = u23**r2.
            u33 = u24**r3.
            u42 = u33**r2.

            u43 = u34**r3.
            u52 = u43**r2.
            u53 = u44**r3.
            u62 = u53**r2.
            u63 = u54**r3.
            u72 = u63**r2.
            u73 = u64**r3.
            u82 = u73**r2.
            u83 = u74**r3.
            u15 = u24.
            u25 = u34.
            u35 = u44.
            u45 = u54.
            u55 = u64.
            u65 = u74.
            u75 = u84.

            s14 = s84.
            s24 = s84.
            s34 = s84.
            s44 = s84.
            s54 = s84.
            s64 = s84.
            s74 = s84.
```

```
A13 = P3*S*RELEASES.
A14 = A13*(1-u13)*(1-s13)*S.
A15 = A14*(1-u14)*(1-s14)*S.

A22 = S20*RELEASES.
A23 = A22*(1-u22)*(1-s22)*S.
A24 = A23*(1-u23)*(1-s23)*S.
A25 = A24*(1-u24)*(1-s24)*S.

A32 = S30*RELEASES.
A33 = A32*(1-u32)*(1-s32)*S.
A34 = A33*(1-u33)*(1-s33)*S.
A35 = A34*(1-u34)*(1-s34)*S.

A42 = S40*RELEASES.
A43 = A42*(1-u42)*(1-s42)*S.
A44 = A43*(1-u43)*(1-s43)*S.
A45 = A44*(1-u44)*(1-s44)*S.

A52 = S50*RELEASES.
A53 = A52*(1-u52)*(1-s52)*S.
A54 = A53*(1-u53)*(1-s53)*S.
A55 = A54*(1-u54)*(1-s54)*S.

A62 = S60*RELEASES.
A63 = A62*(1-u62)*(1-s62)*S.
A64 = A63*(1-u63)*(1-s63)*S.
A65 = A64*(1-u64)*(1-s64)*S.


A72 = S70*RELEASES.
A73 = A72*(1-u72)*(1-s72)*S.
A74 = A73*(1-u73)*(1-s73)*S.
A75 = A74*(1-u74)*(1-s74)*S.

A82 = S80*RELEASES.
A83 = A82*(1-u82)*(1-s82)*S.
A84 = A83*(1-u83)*(1-s83)*S.
A85 = A84*(1-u84)*(1-s84)*S.

IF (CODE == CHAR(Y12)) THEN F = P1*RELEASES.
IF (CODE == CHAR(Y13)) THEN F = u13*A13.
IF (CODE == CHAR(Y14)) THEN F = u14*A14.
IF (CODE == CHAR(Y15)) THEN F = u15*A15.
IF (CODE == CHAR(E12)) THEN F = P2*RELEASES.
IF (CODE == CHAR(E13)) THEN F = s13*(1-u13)*A13.
IF (CODE == CHAR(E14)) THEN F = s14*(1-u14)*A14.
IF (CODE == CHAR(E15)) THEN F = (1-u15)*A15.

IF (CODE == CHAR(Y22)) THEN F = u22*A22.
IF (CODE == CHAR(Y23)) THEN F = u23*A23.
IF (CODE == CHAR(Y24)) THEN F = u24*A24.
IF (CODE == CHAR(Y25)) THEN F = u25*A25.
IF (CODE == CHAR(E22)) THEN F = s22*(1-u22)*A22.
IF (CODE == CHAR(E23)) THEN F = s23*(1-u23)*A23.
IF (CODE == CHAR(E24)) THEN F = s24*(1-u24)*A24.
IF (CODE == CHAR(E25)) THEN F = (1-u25)*A25.

IF (CODE == CHAR(Y32)) THEN F = u32*A32.
IF (CODE == CHAR(Y33)) THEN F = u33*A33.
IF (CODE == CHAR(Y34)) THEN F = u34*A34.
IF (CODE == CHAR(Y35)) THEN F = u35*A35.
IF (CODE == CHAR(E32)) THEN F = s32*(1-u32)*A32.
IF (CODE == CHAR(E33)) THEN F = s33*(1-u33)*A33.
IF (CODE == CHAR(E34)) THEN F = s34*(1-u34)*A34.
IF (CODE == CHAR(E35)) THEN F = (1-u35)*A35.

IF (CODE == CHAR(Y42)) THEN F = u42*A42.
IF (CODE == CHAR(Y43)) THEN F = u43*A43.
IF (CODE == CHAR(Y44)) THEN F = u44*A44.
IF (CODE == CHAR(Y45)) THEN F = u45*A45.
IF (CODE == CHAR(E42)) THEN F = s42*(1-u42)*A42.
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            IF (CODE == CHAR(E43)) THEN F = s43*(1-u43)*A43.
            IF (CODE == CHAR(E44)) THEN F = s44*(1-u44)*A44.
            IF (CODE == CHAR(E45)) THEN F = (1-u45)*A45.


            IF (CODE == CHAR(Y52)) THEN F = u52*A52.
            IF (CODE == CHAR(Y53)) THEN F = u53*A53.
            IF (CODE == CHAR(Y54)) THEN F = u54*A54.
            IF (CODE == CHAR(Y55)) THEN F = u55*A55.
            IF (CODE == CHAR(E52)) THEN F = s52*(1-u52)*A52.
            IF (CODE == CHAR(E53)) THEN F = s53*(1-u53)*A53.
            IF (CODE == CHAR(E54)) THEN F = s54*(1-u54)*A54.
            IF (CODE == CHAR(E55)) THEN F = (1-u55)*A55.

            IF (CODE == CHAR(Y62)) THEN F = u62*A62.
            IF (CODE == CHAR(Y63)) THEN F = u63*A63.
            IF (CODE == CHAR(Y64)) THEN F = u64*A64.
            IF (CODE == CHAR(Y65)) THEN F = u65*A65.
            IF (CODE == CHAR(E62)) THEN F = s62*(1-u62)*A62.
            IF (CODE == CHAR(E63)) THEN F = s63*(1-u63)*A63.
            IF (CODE == CHAR(E64)) THEN F = s64*(1-u64)*A64.
            IF (CODE == CHAR(E65)) THEN F = (1-u65)*A65.

            IF (CODE == CHAR(Y72)) THEN F = u72*A72.
            IF (CODE == CHAR(Y73)) THEN F = u73*A73.
            IF (CODE == CHAR(Y74)) THEN F = u74*A74.
            IF (CODE == CHAR(Y75)) THEN F = u75*A75.
            IF (CODE == CHAR(E72)) THEN F = s72*(1-u72)*A72.
            IF (CODE == CHAR(E73)) THEN F = s73*(1-u73)*A73.
            IF (CODE == CHAR(E74)) THEN F = s74*(1-u74)*A74.
            IF (CODE == CHAR(E75)) THEN F = (1-u75)*A75.

            IF (CODE == CHAR(Y82)) THEN F = u82*A82.
            IF (CODE == CHAR(Y83)) THEN F = u83*A83.
            IF (CODE == CHAR(Y84)) THEN F = u84*A84.
            IF (CODE == CHAR(Y85)) THEN F = u85*A85.
            IF (CODE == CHAR(E82)) THEN F = s82*(1-u82)*A82.
            IF (CODE == CHAR(E83)) THEN F = s83*(1-u83)*A83.
            IF (CODE == CHAR(E84)) THEN F = s84*(1-u84)*A84.
            IF (CODE == CHAR(E85)) THEN F = (1-u85)*A85.

            WT = 1/F.
            IF (CATCHES = 0) THEN (DEV = 2*F).
            IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) >= .001)) THEN
               (DEV = 2*((CATCHES*(LN(CATCHES/F)))-(CATCHES-F))).
            IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) < .001)) THEN
               (DEV = (2-(CATCHES/F))*(((F-CATCHES)**2)/F)).
            XLOSS = DEV.
/ END

/ INPUT                FILE = 'IGHALLY.DAT'.
                       VARIABLES = 3.
                       FORMAT IS FREE.
                       CASES = 120.

/ VARIABLES            NAMES = CODE, CATCHES, RELEASES.
                       LABELS= CODE.

/ REGRESS   DEPENDENT = CATCHES.
            PARAM = 47.
            ITER = 75.
            MEANSQUARE = 1.0.
            WEIGHT = WT.
            LOSS.
            TOLERANCE = .001.


/ TRANSFORM WT = 1.0.

/ PARAM
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NAME =      P1, S20, S30, S40, S50, S60, S70, S80, P2,
            s13, s22, s23, s32, s33, s42, s43,
            s52, s53, s62, s63, s72, s73, s82, s83, s84,
            P3, r2, r3, S3, S4, S5,
            S6, S7, S8, S9, S10, S11,
            u13, u14, u24, u34, u44, u54, u64, u74, u84, u85.

INITIAL = .0001, .02, .02, .02, .02, .02, .02, .02, .0001,
          .2, .05, .2, .05, .2, .05, .2,
          .05, .2, .05, .2, .05, .2, .05, .2, .9,
          .01, 2.5, 1.5, .5, .5, .5,
          .5, .5, .5, .5, .5, .5,
          .2, .4, .4, .4, .4, .4, .4, .4, .4, .4.

MINIMUM = .000001, .0001, .0001, .0001, .0001, .0001, .0001, .0001, .000001,
          .001, .0001, .001, .0001, .001, .0001, .001,
          .0001, .001, .0001, .001, .0001, .001, .0001, .01, .1,
          .00001, .00001, .00001, .00001, .00001, .00001,
          .00001, .00001, .00001, .00001, .00001, .00001,
          .01, .1, .1, .1, .1, .1, .1, .1, .1, .1.

MAXIMUM =  1, .4, .4, .4, .4, .4, .4, .4, 1,
           1, 1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1,
           1, 10, 10, 1, 1, 1,
           1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1, 1.

/ FUNCTION  u22 = u13**r2.
            u23 = u14**r3.
            u32 = u23**r2.
            u33 = u24**r3.
            u42 = u33**r2.
            u43 = u34**r3.
            u52 = u43**r2.
            u53 = u44**r3.
            u62 = u53**r2.
            u63 = u54**r3.
            u72 = u63**r2.
            u73 = u64**r3.
            u82 = u73**r2.
            u83 = u74**r3.
            u15 = u24.
            u25 = u34.
            u35 = u44.
            u45 = u54.
            u55 = u64.
            u65 = u74.
            u75 = u84.

            s14 = s84.
            s24 = s84.
            s34 = s84.
            s44 = s84.
            s54 = s84.
            s64 = s84.
            s74 = s84.

            A13 = P3*RELEASES.
            A14 = A13*(1-u13)*(1-s13)*S3.
            A15 = A14*(1-u14)*(1-s14)*S4.

            A22 = S20*RELEASES.
            A23 = A22*(1-u22)*(1-s22)*S3.
            A24 = A23*(1-u23)*(1-s23)*S4.
            A25 = A24*(1-u24)*(1-s24)*S5.

            A32 = S30*RELEASES.
            A33 = A32*(1-u32)*(1-s32)*S4.
            A34 = A33*(1-u33)*(1-s33)*S5.
            A35 = A34*(1-u34)*(1-s34)*S6.
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A42 = S40*RELEASES.
A43 = A42*(1-u42)*(1-s42)*S5.
A44 = A43*(1-u43)*(1-s43)*S6.
A45 = A44*(1-u44)*(1-s44)*S7.

A52 = S50*RELEASES.
A53 = A52*(1-u52)*(1-s52)*S6.
A54 = A53*(1-u53)*(1-s53)*S7.
A55 = A54*(1-u54)*(1-s54)*S8.

A62 = S60*RELEASES.
A63 = A62*(1-u62)*(1-s62)*S7.
A64 = A63*(1-u63)*(1-s63)*S8.
A65 = A64*(1-u64)*(1-s64)*S9.

A72 = S70*RELEASES.
A73 = A72*(1-u72)*(1-s72)*S8.
A74 = A73*(1-u73)*(1-s73)*S9.
A75 = A74*(1-u74)*(1-s74)*S10.

A82 = S80*RELEASES.
A83 = A82*(1-u82)*(1-s82)*S9.
A84 = A83*(1-u83)*(1-s83)*S10.
A85 = A84*(1-u84)*(1-s84)*S11.

IF (CODE == CHAR(Y12)) THEN F = P1*RELEASES.
IF (CODE == CHAR(Y13)) THEN F = u13*A13.
IF (CODE == CHAR(Y14)) THEN F = u14*A14.
IF (CODE == CHAR(Y15)) THEN F = u15*A15.
IF (CODE == CHAR(E12)) THEN F = P2*RELEASES.
IF (CODE == CHAR(E13)) THEN F = s13*(1-u13)*A13.
IF (CODE == CHAR(E14)) THEN F = s14*(1-u14)*A14.
IF (CODE == CHAR(E15)) THEN F = (1-u15)*A15.

IF (CODE == CHAR(Y22)) THEN F = u22*A22.
IF (CODE == CHAR(Y23)) THEN F = u23*A23.
IF (CODE == CHAR(Y24)) THEN F = u24*A24.
IF (CODE == CHAR(Y25)) THEN F = u25*A25.
IF (CODE == CHAR(E22)) THEN F = s22*(1-u22)*A22.
IF (CODE == CHAR(E23)) THEN F = s23*(1-u23)*A23.
IF (CODE == CHAR(E24)) THEN F = s24*(1-u24)*A24.
IF (CODE == CHAR(E25)) THEN F = (1-u25)*A25.

IF (CODE == CHAR(Y32)) THEN F = u32*A32.
IF (CODE == CHAR(Y33)) THEN F = u33*A33.
IF (CODE == CHAR(Y34)) THEN F = u34*A34.
IF (CODE == CHAR(Y35)) THEN F = u35*A35.
IF (CODE == CHAR(E32)) THEN F = s32*(1-u32)*A32.
IF (CODE == CHAR(E33)) THEN F = s33*(1-u33)*A33.
IF (CODE == CHAR(E34)) THEN F = s34*(1-u34)*A34.
IF (CODE == CHAR(E35)) THEN F = (1-u35)*A35.

IF (CODE == CHAR(Y42)) THEN F = u42*A42.
IF (CODE == CHAR(Y43)) THEN F = u43*A43.
IF (CODE == CHAR(Y44)) THEN F = u44*A44.
IF (CODE == CHAR(Y45)) THEN F = u45*A45.
IF (CODE == CHAR(E42)) THEN F = s42*(1-u42)*A42.
IF (CODE == CHAR(E43)) THEN F = s43*(1-u43)*A43.
IF (CODE == CHAR(E44)) THEN F = s44*(1-u44)*A44.
IF (CODE == CHAR(E45)) THEN F = (1-u45)*A45.

IF (CODE == CHAR(Y52)) THEN F = u52*A52.
IF (CODE == CHAR(Y53)) THEN F = u53*A53.
IF (CODE == CHAR(Y54)) THEN F = u54*A54.
IF (CODE == CHAR(Y55)) THEN F = u55*A55.
IF (CODE == CHAR(E52)) THEN F = s52*(1-u52)*A52.
IF (CODE == CHAR(E53)) THEN F = s53*(1-u53)*A53.
IF (CODE == CHAR(E54)) THEN F = s54*(1-u54)*A54.
IF (CODE == CHAR(E55)) THEN F = (1-u55)*A55.
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          IF (CODE == CHAR(Y62)) THEN F = u62*A62.
          IF (CODE == CHAR(Y63)) THEN F = u63*A63.
          IF (CODE == CHAR(Y64)) THEN F = u64*A64.
          IF (CODE == CHAR(Y65)) THEN F = u65*A65.
          IF (CODE == CHAR(E62)) THEN F = s62*(1-u62)*A62.
          IF (CODE == CHAR(E63)) THEN F = s63*(1-u63)*A63.
          IF (CODE == CHAR(E64)) THEN F = s64*(1-u64)*A64.
          IF (CODE == CHAR(E65)) THEN F = (1-u65)*A65.

          IF (CODE == CHAR(Y72)) THEN F = u72*A72.
          IF (CODE == CHAR(Y73)) THEN F = u73*A73.
          IF (CODE == CHAR(Y74)) THEN F = u74*A74.
          IF (CODE == CHAR(Y75)) THEN F = u75*A75.
          IF (CODE == CHAR(E72)) THEN F = s72*(1-u72)*A72.
          IF (CODE == CHAR(E73)) THEN F = s73*(1-u73)*A73.
          IF (CODE == CHAR(E74)) THEN F = s74*(1-u74)*A74.
          IF (CODE == CHAR(E75)) THEN F = (1-u75)*A75.
          IF (CODE == CHAR(Y82)) THEN F = u82*A82.
          IF (CODE == CHAR(Y83)) THEN F = u83*A83.
          IF (CODE == CHAR(Y84)) THEN F = u84*A84.
          IF (CODE == CHAR(Y85)) THEN F = u85*A85.
          IF (CODE == CHAR(E82)) THEN F = s82*(1-u82)*A82.
          IF (CODE == CHAR(E83)) THEN F = s83*(1-u83)*A83.
          IF (CODE == CHAR(E84)) THEN F = s84*(1-u84)*A84.
          IF (CODE == CHAR(E85)) THEN F = (1-u85)*A85.

          WT = 1/F.
          IF (CATCHES = 0) THEN (DEV = 2*F).
          IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) >= .001)) THEN
             (DEV = 2*((CATCHES*(LN(CATCHES/F)))-(CATCHES-F))).
          IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) < .001)) THEN
             (DEV = (2-(CATCHES/F))*(((F-CATCHES)**2)/F)).
          XLOSS = DEV.
/ END

/ INPUT                FILE = 'IGHALLY.DAT'.
                       VARIABLES = 3.
                       FORMAT IS FREE.
                       CASES = 120.

/ VARIABLES            NAMES = CODE, CATCHES, RELEASES.
                       LABELS= CODE.

/ REGRESS   DEPENDENT = CATCHES.
            PARAM = 54.
            ITER = 75.
            MEANSQUARE = 1.0.
            WEIGHT = WT.
            LOSS.
            TOLERANCE = .001.

/ TRANSFORM WT = 1.0.

/ PARAM

  NAME =      P1, S20, S30, S40, S50, S60, S70, S80, P2,
              s13, s14, s22, s23, s24, s32, s33, s34,
                        s42, s43, s44, s52, s53, s54,
                        s62, s63, s64, s72, s73, s74,
                        s82, s83, s84,
              P3, r2, r3, S3, S4, S5,
              S6, S7, S8, S9, S10, S11,
              u13, u14, u24, u34, u44, u54, u64, u74, u84, u85.

  INITIAL = .0001, .02, .02, .02, .02, .02, .02, .02, .0001,
            .2, .9, .05, .2, .9, .05, .2, .9,
                    .05, .2, .9, .05, .2, .9,
                    .05, .2, .9, .05, .2, .9,
                    .05, .2, .9,
            .01, 2.5, 1.5, .5, .5, .5,
            .5, .5, .5, .5, .5, .5,
            .2, .4, .4, .4, .4, .4, .4, .4, .4, .4.
```

```
MINIMUM = .000001, .0001, .0001, .0001, .0001, .0001, .0001, .0001, .000001,
          .001, .01, .0001, .001, .01, .0001, .001, .01,
                    .0001, .001, .01, .0001, .001, .01,
                    .0001, .001, .01, .0001, .001, .01,
                    .0001, .001, .01,
          .00001, .00001, .00001, .00001, .00001, .00001,
          .00001, .00001, .00001, .00001, .00001, .00001,
          .01, .1, .1, .1, .1, .1, .1, .1, .1, .1.

MAXIMUM =  1, .4, .4, .4, .4, .4, .4, .4, 1,
           1, 1, 1, 1, 1, 1, 1, 1,
                 1, 1, 1, 1, 1, 1,
                 1, 1, 1, 1, 1, 1,
                 1, 1, 1,
           1, 10, 10, 1, 1, 1,
           1, 1, 1, 1, 1, 1,
           1, 1, 1, 1, 1, 1, 1, 1, 1, 1.

/ FUNCTION  u22 = u13**r2.
            u23 = u14**r3.
            u32 = u23**r2.
            u33 = u24**r3.
            u42 = u33**r2.
            u43 = u34**r3.
            u52 = u43**r2.
            u53 = u44**r3.
            u62 = u53**r2.
            u63 = u54**r3.
            u72 = u63**r2.
            u73 = u64**r3.
            u82 = u73**r2.
            u83 = u74**r3.
            u15 = u24.
            u25 = u34.
            u35 = u44.
            u45 = u54.
            u55 = u64.
            u65 = u74.
            u75 = u84.

            A13 = P3*RELEASES.
            A14 = A13*(1-u13)*(1-s13)*S3.
            A15 = A14*(1-u14)*(1-s14)*S4.

            A22 = S20*RELEASES.
            A23 = A22*(1-u22)*(1-s22)*S3.
            A24 = A23*(1-u23)*(1-s23)*S4.
            A25 = A24*(1-u24)*(1-s24)*S5.

            A32 = S30*RELEASES.
            A33 = A32*(1-u32)*(1-s32)*S4.
            A34 = A33*(1-u33)*(1-s33)*S5.
            A35 = A34*(1-u34)*(1-s34)*S6.

            A42 = S40*RELEASES.
            A43 = A42*(1-u42)*(1-s42)*S5.
            A44 = A43*(1-u43)*(1-s43)*S6.
            A45 = A44*(1-u44)*(1-s44)*S7.

            A52 = S50*RELEASES.
            A53 = A52*(1-u52)*(1-s52)*S6.
            A54 = A53*(1-u53)*(1-s53)*S7.
            A55 = A54*(1-u54)*(1-s54)*S8.

            A62 = S60*RELEASES.
            A63 = A62*(1-u62)*(1-s62)*S7.
            A64 = A63*(1-u63)*(1-s63)*S8.
            A65 = A64*(1-u64)*(1-s64)*S9.

            A72 = S70*RELEASES.
            A73 = A72*(1-u72)*(1-s72)*S8.
            A74 = A73*(1-u73)*(1-s73)*S9.
            A75 = A74*(1-u74)*(1-s74)*S10.
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A82 = S80*RELEASES.
A83 = A82*(1-u82)*(1-s82)*S9.
A84 = A83*(1-u83)*(1-s83)*S10.
A85 = A84*(1-u84)*(1-s84)*S11.

IF (CODE == CHAR(Y12)) THEN F = P1*RELEASES.
IF (CODE == CHAR(Y13)) THEN F = u13*A13.
IF (CODE == CHAR(Y14)) THEN F = u14*A14.
IF (CODE == CHAR(Y15)) THEN F = u15*A15.
IF (CODE == CHAR(E12)) THEN F = P2*RELEASES.
IF (CODE == CHAR(E13)) THEN F = s13*(1-u13)*A13.
IF (CODE == CHAR(E14)) THEN F = s14*(1-u14)*A14.
IF (CODE == CHAR(E15)) THEN F = (1-u15)*A15.

IF (CODE == CHAR(Y22)) THEN F = u22*A22.
IF (CODE == CHAR(Y23)) THEN F = u23*A23.
IF (CODE == CHAR(Y24)) THEN F = u24*A24.
IF (CODE == CHAR(Y25)) THEN F = u25*A25.
IF (CODE == CHAR(E22)) THEN F = s22*(1-u22)*A22.
IF (CODE == CHAR(E23)) THEN F = s23*(1-u23)*A23.
IF (CODE == CHAR(E24)) THEN F = s24*(1-u24)*A24.
IF (CODE == CHAR(E25)) THEN F = (1-u25)*A25.

IF (CODE == CHAR(Y32)) THEN F = u32*A32.
IF (CODE == CHAR(Y33)) THEN F = u33*A33.
IF (CODE == CHAR(Y34)) THEN F = u34*A34.
IF (CODE == CHAR(Y35)) THEN F = u35*A35.
IF (CODE == CHAR(E32)) THEN F = s32*(1-u32)*A32.
IF (CODE == CHAR(E33)) THEN F = s33*(1-u33)*A33.
IF (CODE == CHAR(E34)) THEN F = s34*(1-u34)*A34.
IF (CODE == CHAR(E35)) THEN F = (1-u35)*A35.

IF (CODE == CHAR(Y42)) THEN F = u42*A42.
IF (CODE == CHAR(Y43)) THEN F = u43*A43.

IF (CODE == CHAR(Y44)) THEN F = u44*A44.
IF (CODE == CHAR(Y45)) THEN F = u45*A45.
IF (CODE == CHAR(E42)) THEN F = s42*(1-u42)*A42.
IF (CODE == CHAR(E43)) THEN F = s43*(1-u43)*A43.
IF (CODE == CHAR(E44)) THEN F = s44*(1-u44)*A44.
IF (CODE == CHAR(E45)) THEN F = (1-u45)*A45.


IF (CODE == CHAR(Y52)) THEN F = u52*A52.
IF (CODE == CHAR(Y53)) THEN F = u53*A53.
IF (CODE == CHAR(Y54)) THEN F = u54*A54.
IF (CODE == CHAR(Y55)) THEN F = u55*A55.
IF (CODE == CHAR(E52)) THEN F = s52*(1-u52)*A52.
IF (CODE == CHAR(E53)) THEN F = s53*(1-u53)*A53.
IF (CODE == CHAR(E54)) THEN F = s54*(1-u54)*A54.
IF (CODE == CHAR(E55)) THEN F = (1-u55)*A55.

IF (CODE == CHAR(Y62)) THEN F = u62*A62.
IF (CODE == CHAR(Y63)) THEN F = u63*A63.
IF (CODE == CHAR(Y64)) THEN F = u64*A64.
IF (CODE == CHAR(Y65)) THEN F = u65*A65.
IF (CODE == CHAR(E62)) THEN F = s62*(1-u62)*A62.
IF (CODE == CHAR(E63)) THEN F = s63*(1-u63)*A63.
IF (CODE == CHAR(E64)) THEN F = s64*(1-u64)*A64.
IF (CODE == CHAR(E65)) THEN F = (1-u65)*A65.

IF (CODE == CHAR(Y72)) THEN F = u72*A72.
IF (CODE == CHAR(Y73)) THEN F = u73*A73.
IF (CODE == CHAR(Y74)) THEN F = u74*A74.
IF (CODE == CHAR(Y75)) THEN F = u75*A75.
IF (CODE == CHAR(E72)) THEN F = s72*(1-u72)*A72.
IF (CODE == CHAR(E73)) THEN F = s73*(1-u73)*A73.
IF (CODE == CHAR(E74)) THEN F = s74*(1-u74)*A74.
IF (CODE == CHAR(E75)) THEN F = (1-u75)*A75.
```

```
    IF (CODE == CHAR(Y82)) THEN F = u82*A82.
    IF (CODE == CHAR(Y83)) THEN F = u83*A83.
    IF (CODE == CHAR(Y84)) THEN F = u84*A84.
    IF (CODE == CHAR(Y85)) THEN F = u85*A85.
    IF (CODE == CHAR(E82)) THEN F = s82*(1-u82)*A82.
    IF (CODE == CHAR(E83)) THEN F = s83*(1-u83)*A83.
    IF (CODE == CHAR(E84)) THEN F = s84*(1-u84)*A84.
    IF (CODE == CHAR(E85)) THEN F = (1-u85)*A85.

    WT = 1/F.

    IF (CATCHES = 0) THEN (DEV = 2*F).
    IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) >= .001)) THEN
       (DEV = 2*((CATCHES*(LN(CATCHES/F)))-(CATCHES-F))).
    IF ((CATCHES > 0) AND ((ABS(1-(CATCHES/F))) < .001)) THEN
       (DEV = (2-(CATCHES/F))*(((F-CATCHES)**2)/F)).

    XLOSS = DEV.

/ END
```

Appendix Table C1. Estimated survival rates to age 2 (S_{i0}) for indicated brood years (**Years**) and estimated conditional ocean survival rates (S_i) from fall of year i to late spring of year i+1 (**Years**) for fall chinook salmon released from Iron Gate Hatchery. Listed standard errors are unadjusted estimates reported by **BMDP**, and BMDP estimates adjusted by the square root of the estimated ϕ (**Adjusted**). Confidence bounds are calculated as $\pm$ 2 · adjusted standard errors. Only point estimates are presented for parameter estimates equal to imposed constraints. Estimates are based on CWT releases made in eight successive brood years (1978 through 1985.). Accepted model (Model 3) assumes equal age four maturation probability for all groups, but allows ocean survival rates to vary (m = 47).

			Standard Error		95% Confidence Limit	
Parameter	Years	Estimate	BMDP	Adjusted	Lower	Upper
Survival to Age 2						
S_{10}	1978	0.1351[a]	na	na	na	na
S_{20}	1979	0.4000	---	---	---	---
S_{30}	1980	0.0523	0.0044	0.0179	0.0166	0.0880
S_{40}	1981	0.0082	0.0003	0.0011	0.0060	0.0103
S_{50}	1982	0.1068	0.0048	0.0197	0.0674	0.1462
S_{60}	1983	0.4000	---	---	---	---
S_{70}	1984	0.0854	0.0084	0.0341	0.0171	0.1537
S_{80}	1985	0.0519	0.0040	0.0164	0.0192	0.0846
Ocean Survival Rate						
S_3	1981-82	0.1409	0.0181	0.07398	0.0000	0.2888
S_4	1982-83	0.2664	0.0212	0.08660	0.0932	0.4396
S_5	1983-84	1.0000	---	---	---	---
S_6	1984-85	1.0000	---	---	---	---
S_7	1985-86	0.1456	0.0083	0.0338	0.0779	0.2133
S_8	1986-87	0.6923	0.0505	0.2063	0.2798	1.0000
S_9	1987-88	0.4997	0.0369	0.1507	0.1983	0.8011
S_{10}	1988-89	1.0000	---	---	---	---
S_{11}	1989-90	0.4220	0.0832	0.3396	0.0000	1.0000

[a] A minimum estimate based on the estimate of the confounded parameter P_3, assuming that u_{12} and σ_{12} were both approximately zero for release group 1.

Appendix Table C2. Estimated maturation probabilities at age 2 (σ_{i2}) and age 3 (σ_{i3}) for 1978 through 1985 brood year (**Brood**) releases of yearling fall chinook salmon from Iron Gate Hatchery, and estimated maturation probability at age 4 (σ_{i4}) for all groups combined. Listed standard errors are unadjusted estimates reported by **BMDP**, and BMDP estimates adjusted by the square root of the estimated ϕ (**Adjusted**). Confidence bounds are calculated as ± 2 · adjusted standard errors. Only point estimates are presented for parameter estimates equal to imposed constraints. Estimates are based on CWT releases made in eight successive brood years (1978 through 1985.). Accepted model (Model 3) assumes equal age four maturation probability for all groups, but allows ocean survival rates to vary (m = 47). Note that no estimate of maturation probability at age 2 can be made for the first release group (1978 brood).

			Standard Error		95% Confidence Limit	
Parameter	Brood	Estimate	BMDP	Adjusted	Lower	Upper
σ_{13}	1978	0.0178	0.0013	0.0052	0.0074	0.0283
σ_{22}	1979	0.0008	0.0001	0.0006	0.0000	0.0129
σ_{23}	1979	0.0729	0.0064	0.0263	0.0203	0.1255
σ_{32}	1980	0.0145	0.0022	0.0086	0.0000	0.0317
σ_{33}	1980	0.1969	0.0131	0.0535	0.0899	0.3039
σ_{42}	1981	0.0030	0.0018	0.0071	0.0000	0.0173
σ_{43}	1981	0.1139	0.0108	0.0441	0.0257	0.2021
σ_{52}	1982	0.0105	0.0009	0.0038	0.0028	0.0182
σ_{53}	1982	0.1071	0.0059	0.0242	0.0587	0.1555
σ_{62}	1983	0.0011	0.0001	0.0005	0.0001	0.0022
σ_{63}	1983	0.1095	0.0079	0.0322	0.0451	0.1738
σ_{72}	1984	0.0108	0.0015	0.0063	0.0000	0.0234
σ_{73}	1984	0.1020	0.0080	0.0325	0.0371	0.1669
σ_{82}	1985	0.0028	0.0008	0.0032	0.0000	0.0092
σ_{83}	1985	0.0909	0.0063	0.0256	0.0397	0.1421
σ_{i4}	1978-85	0.9240	0.0047	0.0191	0.8859	0.9621

Appendix Table C3. Estimated exploitation rates at age 4 for coded wire tagged fall chinook salmon released as yearlings from Iron Gate Hatchery, brood years 1978 through 1985. Listed standard errors are unadjusted estimates reported by **BMDP,** and BMDP estimates adjusted by the square root of the estimated ϕ (**Adjusted**). Confidence bounds are calculated as ± 2 · adjusted standard errors. Only point estimates are presented for parameter estimates equal to imposed constraints. Estimates are based on CWT releases made in eight successive brood years (1978 through 1985.). Accepted model (Model 3) assumes equal age four maturation probability for all groups, but allows ocean survival rates to vary (m = 47).

Year of		Standard Error		95% Confidence Limit	
Fishery	Estimate	BMDP	Adjusted	Lower	Upper
1982	0.5998	0.0081	0.0332	0.5334	0.6661
1983	0.6162	0.0093	0.0381	0.5858	0.6924
1984	0.4909	0.0108	0.0442	0.4025	0.5793
1985	0.4575	0.0103	0.0420	0.3736	0.5414
1986	0.5039	0.0098	0.0399	0.4241	0.5837
1987	0.5484	0.0069	0.0282	0.4921	0.6047
1988	0.5204	0.0077	0.0314	0.4576	0.5832
1989	0.5043	0.0115	0.0468	0.4108	0.5978

Appendix Table C4. Estimated survival rates to age 2 (S_{i0}) for indicated brood years (**Years**) and estimated conditional ocean survival rates (S_i) from fall of year i to late spring of year i+1 (**Years**) for fall chinook salmon released from Trinity River Hatchery. Listed standard errors are unadjusted estimates reported by **BMDP**, and BMDP estimates adjusted by the square root of the estimated ϕ (**Adjusted**). Confidence bounds are calculated as $\pm 2 \cdot$ adjusted standard errors. Only point estimates are presented for parameter estimates equal to imposed constraints. Estimates are based on CWT releases made in eight successive brood years (1978 through 1985.). Accepted model (Model 3) assumes equal age four maturation probability for all groups, but allows ocean survival rates to vary (m = 47).

			Standard Error		95% Confidence Limit	
Parameter	Years	Estimate	BMDP	Adjusted	Lower	Upper
Survival to Age 2						
S_{20}	1979	0.4000	---	---	---	---
S_{30}	1980	0.1174	0.0114	0.0375	0.0423	0.1925
S_{40}	1981	0.0086	0.0012	0.0039	0.0008	0.0164
S_{50}	1982	0.0325	0.0091	0.0300	0.0234	0.0923
S_{60}	1983	0.4000	---	---	---	---
S_{70}	1984	0.0674	0.0008	0.0027	0.0619	0.0728
S_{80}	1985	0.0722	0.0060	0.0197	0.0329	0.1115
Ocean Survival Rate						
S_3	1981-82	0.1905	0.0135	0.0444	0.1017	0.2790
S_4	1982-83	0.1564	0.0161	0.0530	0.0504	0.2623
S_5	1983-84	1.0000	---	---	---	---
S_6	1984-85	0.9681	0.2836	0.9329	0.0000	1.0000
S_7	1985-86	0.2880	0.0027	0.0089	0.2702	0.3058
S_8	1986-87	1.0000	---	---	---	---
S_9	1987-88	1.0000	---	---	---	---
S_{10}	1988-89	0.7535	0.1666	0.5480	0.0000	1.0000
S_{11}	1989-90	1.0000	---	---	---	---

Appendix Table C5. Estimated maturation probabilities at age 2 (σ_{i2}) and age 3 (σ_{i3}) for 1978 through 1985 brood year (**Brood**) releases of yearling fall chinook salmon from Trinity River Hatchery, and estimated maturation probability at age 4 (σ_{i4}) for all groups combined. Listed standard errors are unadjusted estimates reported by **BMDP**, and BMDP estimates adjusted by the square root of the estimated ϕ (**Adjusted**). Confidence bounds are calculated as ± 2 · adjusted standard errors. Only point estimates are presented for parameter estimates equal to imposed constraints. Estimates are based on CWT releases made in eight successive brood years (1978 through 1985.). Accepted model (model 3) assumes equal age four maturation probability for all groups, but allows ocean survival rates to vary (m = 47). Note that no estimate of maturation probability at age 2 can be made for the first release group (1978 brood).

			Standard Error		95% Confidence Limit	
Parameter	Brood	Estimate	BMDP	Adjusted	Lower	Upper
σ_{13}	1978	0.2427	0.0158	0.0520	0.1387	0.3467
σ_{22}	1979	0.0106	0.0005	0.0018	0.0070	0.0142
σ_{23}	1979	0.0989	0.0094	0.0309	0.0371	0.1607
σ_{32}	1980	0.0855	0.0087	0.0285	0.0285	0.1425
σ_{33}	1980	1.0000	---	---	---	---
σ_{42}	1981	0.0625	0.0000	---	---	---
σ_{43}	1981	0.4713	0.0753	0.2477	0.0241	0.9667
σ_{52}	1982	0.0508	0.0147	0.0484	0.0000	0.1475
σ_{53}	1982	0.3749	0.0135	0.0444	0.2861	0.4637
σ_{62}	1983	0.0403	0.0010	0.0033	0.0337	0.0469
σ_{63}	1983	0.7492	0.0048	0.0158	0.7176	0.7808
σ_{72}	1984	0.0697	0.0032	0.0105	0.0486	0.0907
σ_{73}	1984	0.7170	0.0063	0.0207	0.6756	0.7584
σ_{82}	1985	0.0527	0.0051	0.0168	0.0191	0.0863
σ_{83}	1985	0.5570	0.0549	0.1806	0.1958	0.9182
σ_{i4}	1978-85	0.9884	0.0019	0.0062	0.9760	1.0000

Appendix Table C6. Estimated exploitation rates at age 4 for coded wire tagged fall chinook salmon released as yearlings from Trinity River Hatchery, brood years 1978 through 1985. Listed standard errors are unadjusted estimates reported by **BMDP,** and BMDP estimates adjusted by the square root of the estimated ϕ (**Adjusted**). Confidence bounds are calculated as $\pm$ 2 · adjusted standard errors. Only point estimates are presented for parameter estimates equal to imposed constraints. Estimates are based on CWT releases made in eight successive brood years (1978 through 1985.). Accepted model (Model 3) assumes equal age four maturation probability for all groups, but allows ocean survival rates to vary (m = 47).

Year of Fishery	Estimate	Standard Error		95% Confidence Limit	
		BMDP	Adjusted	Lower	Upper
1982	0.5086	0.0148	0.0487	0.4112	0.6060
1983	0.4968	0.0109	0.0358	0.4252	0.5685
1984	0.3548	0.0282	0.0928	0.1692	0.5403
1985	0.4676	0.0109	0.0358	0.3960	0.5392
1986	0.5925	0.0081	0.0266	0.5393	0.6457
1987	0.4842	0.0083	0.0273	0.4296	0.5388
1988	0.4210	0.0121	0.0398	0.3414	0.5006
1989	0.4371	0.0112	0.0368	0.3635	0.5107