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ADULT SALMONID PIT-TAG RETURNS TO COLUMBIA RIVER'S LOWER GRANITE DAM

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Executive Summary

The following statements summarize the results of an analysis of the returns of PIT-tagged Snake River spring chinook. and steelhead detected at Lower Granite Dam as well as theoretical work on statistical power calculations for tests of return rates. The phrase return rate will be taken to mean return and *detection* rate. Knowledge that a fish has returned depends upon it being detected at Lower Granite Dam. Some returns are unaccounted for because they go through the navigation lock or manage to go through the adult bypass undetected.

1. Adult PIT tag recoveries to date are informative at least from a qualitative perspective. Information about freshwater residence and marine residence times, and other behavior, can be provided by the juvenile and adult detection history. E.g., a pair of chinook tagged at the same location on the same date travelled through a juvenile detection facility on the same day 9 months later and then returned to Lower Granite Dam as adults on the same day 2 years later.

2. The tagging levels by geographic region, rearing type, and, for chinook, life history stage have varied considerably since PIT tagging began on the Columbia River system. Early tagging studies were directed more at addressing juvenile problems rather than assessing adult return rates. As a result of this variation in tagging levels and scope, comparisons in adult return rates between years, regions, etc., are made more difficult, since many of the potential interactions cannot be estimated. Global conclusions about the effect of potential treatments and/or natural factors, such as region of origin, on adult return rates are difficult to make until a more balanced, more consistent tagging study is implemented.

3. Along the same lines, tagging levels will need to be increased considerably if experiments are to be conducted to determine factors that affect return rates. E.g., if the existing return rate, prior to *treatment*, is 0.0002, consistent with some spring chinook releases, and the treatment increases the survival rate to 0.0005, approximately 46,000 fish in both the control and the treatment groups need to be PIT-tagged to detect a statistically significant difference with 80% probability.

4. Analysis of the available data suggests that life stage (parr or smolt), rearing type (hatchery or wild), and geographic location all affect the return rates for spring chinook. The data are too limited, however: to assess the potential interaction effects thoroughly; e.g., how does geographic origin interact with rearing type?

5. Return rates for Snake River steelhead are roughly an order of magnitude greater than Snake River spring chinook return rates.

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1 Introduction

Wild and hatchery-reared salmonids in the Columbia River and Snake River systems have been tagged with Passive Integrated Transponder (PIT) tags since 1985, with the first substantial numbers of tags being released in 1987. Most of these tagging efforts have been aimed at providing information about juvenile movement and survival downstream. Since then a number of these PIT-tagged fish have returned to the Columbia River.

Lower Granite Dam is the sole facility on the Columbia River system that possesses a PIT tag detector for returning salmonids and steelhead and it thus provides some information about some of the returning adults. Not all returns to Lower Granite Dam are counted, however, as some go through the navigation locks and some go through the adult bypass facility without being detected. For those fish electronically detected, the time of arrival and their individual tag codes have been stored in a computer database named PTAGIS2, which is maintained by the Pacific States Marine Fisheries Commission.

The purposes of this report are threefold:

- To present summary tables and some general observations about the adult PIT returns to Lower Granite Dam;
- To demonstrate, using the currently available information on Snake River spring chinook and summer steelhead, statistical methods for analyzing return rates of PIT-tagged salmonids;
- To discuss procedures for determining the number of fish to tag to achieve a particular power for hypothesis tests of equai return rates for two treatment groups. (For a related report see Newman (1995a).)

We emphasize that the second purpose, an analysis of return rates! is a demonstration of how to analyze returns, because of the relatively smail sample sizes currently avaiiabie. (However, for a re-analysis of this data incorporating Bayesian methods see Newman (1995b).)

We begin the next section with a discussion of various ways of categorizing the returns, thus identifying factors possibly relevant to statistical summary and analysis. Next, summaries of the returns are presented, categorized by the factors thought most essential, such as species and run. Following that, relatively simple statistical comparisons of returns, both graphically and analytically via generalized linear models (see, for example, Generalized *Linear Models, 2nd Edition*, by McCullagh and Nelder, 1989), are presented. A technical appendix is attached that describes methodology for determining tagging levels for hypothesis testing. additional appendices contain listings of individual adult chinook and steelhead that has returned to Lower Granite Dam as of August 4, 1993.

2 Potentially influential factors

The primary level of distinction in any analysis of return rates is species. Most of the PIT tagging in the Columbia and Snake River systems has been done with chinook salmon and steelhead, but some sockeye and coho salmon have been PIT-tagged, too.

Within a given species several factors could be considered for summarization and analysis of adult PIT returns: .

1. Recovery year: year the aduit fish returned to the river
2. Brood year: year the eggs were laid
3. Migration year (MY): year the juvenile fish migrate seaward
4. Race: spring, summer, fall, and winter
5. Rearing type (RT): hatchery, wild, unknown
6. Geographic origin/site of release (depends on stocks of interest):
   (a) Snake: Clearwater
   (b) Snake: Saimon
   (c) Snake: Grande Ronde
   (d) Snake: Mainstem
   (e) Columbia: Upper
   (f) Columbia: Below Lower Granite Dam

The *unknown* categorization of rearing type typically refers to fish that are intercepted by traps downstream of hatcheries and natural spawning areas but cannot be identified as being either hatchery or wild fish.

The summaries that follow focus on spring chinook and summer steelhead from the Snake River system. The analysis of return rates for both species will evaluate the effects of migration year, rearing type, and geographic origin. For spring chinook the migration years are 1989, 1990, and 1991 and the geographic origins are the Clearwater, the Salmon, and the Grande Ronde rivers. For summer steelhead the migration years are 1989 and 1990 and the origins are the Clearwater, the Salmon, and the Snake River trap. Data from the early years of PIT tagging, namely migration years prior to 1989, were excluded from anaiyses because of the low release numbers and spottiness of the geographic' coverage.

3 Snake River chinook and steelhead data summaries

The data source for releases and adult returns of PIT salmonids is the Pacific State Marine Fisheries Commission's PIT database, PTAGIS2. Unfortunately, the release data files are not complete because of missing data in many of the key fields such as release site or tag site. As a consequence, releases tabulated by particular selection criteria using PTAGIS2's report generating programs are sometimes erroneous, generally underestimating the totals. More accurate

Table 1: Snake River spring chinook releases

Run	Rearing type	Drainage	Life Stage	MY 1989	MY 1990	MY 1991
Spring	Hatchery	Clearwater	Parr	9,514	8,858	17,656
			Smolt	4,698	3,076	2.439
		Salmon	Parr	5,690	9,121	6,406
			Smolt	6,493	0	7,502
		Grande Ronde	Parr	0	0	0
			Smolt	10,017	0	0
	Wild	Clearwater	Parr	5,031	0	1,172
			Smolt	0	31	0
		Salmon				
			Parrsmolt	8,364 0	12.195 30	7,426 12
		Grande Ronde	Parr	2,993	a4	2,030
			Smolt	0	0	0
	Unknown	Clearwater		908	6,756	322
		Salmon		645	7,367	414
		Grande Ronde		0	0	0

tallies can be extracted by an exhaustive and tedious search of the release files by single criterion, such as release site, then tag site, then river kilometer, then tagging coordinator, for instance, and then cross-referencing the results. The recovery information, on the other hand, is reiatively complete.

3.1 Release data

Release data for a subset of the Snake- River spring chinook releases, migration years 1989-1991 from the three principal drainages of the Snake River, are shown in Table 1. The spring releases were tallied by examining every release group from every identified release site and tag site listed in PTAGIS2. The parr-smolt distinction is made by calling every fish tagged in the calendar year prior to the migration year a parr and anything tagged during the migration year a smoit. This was only done for the hatchery and wild stocks.

Note that the within drainage release numbers have varied considerably between years. Unfortunately for comparison purposes, there were no Grande Ronde hatchery releases for the migration years 1990 and 1991. These missing values confound analysis of interactions between migration year and geographic origin. Xlso note that the 1990 wild releases from the Clearwater and Grande Ronde were so low that returns are extremely unlikely.

Release data for Snake River summer run steelhead are, shown in Table 2. Releases from Snake River Trap, located in the mainstem of the Snake River, are shown in addition to the three main drainages given for spring chinook. The Grande Ronde drainage is listed but, based on PTAGIS2 information, neither hatchery nor wild steelhead have ever been PIT-tagged and released from there.

Appendix 8 provides more detail as to where the numbers for both the spring chinook and summer steelhead releases came from. Essentially any release groups that fell in one of the above cross-classification cells were included.

Table 2: Snake River summer steelhead releases

Run	Rearing type	Drainage	MY 1989	MY 1990	MY 1991
Summer	Hatchery	Clearwater	3,561	4.186	4,279
		Salmon	5,964	0	
		Grande Ronde	0	0	6,025 0
		Snake Trap	2,725	3,193	2,692
	Wild	Clearwater	1,328	1,417	1,676
		Salmon	893	1	54
		Grande Ronde	0	0	0
		Snake Trap	1.794	3,079	3.628

Table 3: Adult returns through August 4, 1993

Migration Year	Chinook	Steelhead
1987	2	15
1988	18	35
	23	64
1989 1990	29	75
1991	21	52
Ttls	80	241

3.2 Return data

Table 3 shows all the adult chinook and steelhead returns detected at Lower Granite Dam as of August 4, 1993 by migration year. The (spring, summer; and unknown run) chinook returns, divided into returns from releases at the parr and smolt stages, from the three Snake River drainages are shown in Table 4. As was mentioned earlier, there were no Grande Ronde spring hatchery chinook during migration years 1990 and 1991 and no spring unknown chinook releases, therefore no returns are possible in those categories.

Similarly summer steelhead returns for releases from the Clearwater and Salmon Rivers drainages, as well as the Snake Trap, are given in Table 5. Only returns from two migration years are given, 1989 and 1990; many of the 1991 migration group may not return until the fall of 1993 and spring of 1994.

Table 4: Adult spring chinook returns (#parr:#smolt) through August 4, 1993

Run	Rearing type	Drainage	MY 1989	MY 1990	MY 1991	Total	Total Release	Total Return Rate
Spring	Hatchery	Clearwater	(0:1)	(2:1)	(4:4)	12	46,241	3.000360
		Salmon / Grande Ronde	(0:1) (NA:9)	(NA:0) (7:0)	(0:NA) (2:0)	2 9	[illegible]	[illegible]
	Wild	Clearwater	(1:NA)			1	6,237	0.000160
		Salmon	(3:NA)	.		12	28,027	0.000428
		Grande Ronde	(2:NA)	(0:NA)	(2:NA)	4	5,107	0.000783
	Unknown	Clearwater	0	2	0	7	9,566	5.000209
		Salmon	2	5	0	NA	8,426	0.000831
		Grande Ronde	NA	NA	NA		NA	NA

Table 5: Adult steelhead returns through August 4, 1993

Run	Rearing type	Drainage	MY 1989	MY 1990	Total	Total Release	Total Return Rate
Summer	Hatchery	Clearwater	19	25	44	7,746	0.00568
		Salmon	13	NA	13	5,964	0.00218
		Snake Trap	0	23	27	5,918	0.00456
	Wild	Clearwater	1	3	3	2,745	0.00109
		Salmon		0	1	NA	NA
		Snake Trap	6	22	28	4.873	0.00575

A comparison of return rates shows that the steelhead return rates are considerably higher than chinook return rates, typically an order of magnitude greater.

Appendices 9 and 10 are detailed listings of every adult chinook and steelhead return, respectively, to Lower Granite Dam through August 4, 1993.

3.3 Comments

In addition to the significant between species difference in return rates for summer steelhead and spring chinook! there are some interesting somewhat anecdotal cases worth mentioning.

Most of the spring and summer chinook returns were either age 4 or 5, where age is calculated by subtracting brood year (2 years prior to migration year for spring and summer chinook) from return year. For example the first return in Table 13 (in Appendix 9) arrived on May 8, 1989; its brood year was 1985, so it is called a 4 year old fish. The only 6 year old fish (ID 7F7E432067) was a wild spring chinook caught and released August 15, 1988 in the Salmon River and detected at Lower Granite dam on May 29, 1993. This fish is also interesting in that it was detected at Lower Granite Dam juvenile detector on May 1, 1991, presumably during outmigration, suggesting that it spent over 3 years in freshwater.

There were two wild spring chinook from the Salmon River drainage (Marsh Creekj that were tagged the same day, August 13, 1989, passed through the Lower Granite Dam juvenile detection facility nine months later on the same day, May 12, 1990, and then came back through the Lower Granite Dam adult detection facility two years later, again on the same day, May 8, 1992! The actual times they passed through the detection facilities differed by 4 to 7 hours. There was another pair of hatchery spring chinook released from the Clearwater trap on October 9, 1990, which also returned on the same day, June 2, 1993, but only one of the pair was detected during outmigration.

There were several pairs of steelhead tagged the same date and returning to Lower Granite Dam the same date, but the downstream passage times either did not overlap or were not detected.

hnother intriguing case for steelhead was fish 7F7E4C0508 which was detected at Lower Granite Dam on September 17, 1989, again on March 30, 1990, and then again on April 9, 1990. This fish, of unknown run and rearing type, was released at Ice Harbor Dam (on the lower Snake River below Lower Granite Dam) on March 24, 1988.

4 Analysis of return rates

In this section we will demonstrate how to compare the return rates between different sets of release groups, using geographic origin, migration year, and rearing type as covariates. Separate analyses will be done for spring chinook and summer steelhead. The chinook analyses will include an additional covariate, parr or smolt classification; this is to account for overwintering mortality. We emphasize that this analysis is more a demonstration than a statement of definitive conclusions about return rates because of the small sample sizes, quality control problems with the database, the fact that some returning PIT-tagged fish are not detected, and the likelihood that returns from more recent migration years are not complete. As mentioned previously the rates are actually rates of return and detection combined.

We will first examine the hatchery and wild spring chinook that were released from one of three Snake River drainages, Clearwater, Salmon, and Grande Ronde. The relevant data comes from Tables 1 and 4. The returns from migration years 1990 and 1991 are likely not complete. Later arrivals are possible; note that a 1989 release arrived in 1993 (and are included in the analysis of Newman (1995b)). The aggregation by migration year of the releases and returns even within the same race, rearing type and geographic area is still somewhat crude. because the date of tagging may have an effect as well. For example, fish with rhe same migration year may have been tagged in October of the preceding year or February of the migration year and freshwater mortality between October and February is being ignored. A parr-smolt classification, described earlier, is an attempt to account for this overwintering mortality. Furthermore the date of tagging often differs from the date of release. A more detailed analysis would be to treat tagging date as a covariate. Unfortunately, the data would be even more sparse.

Then we will analyze the hatchery and wild summer steelhead, returns of groups released from the Clearwater and Salmon drainages, as well as from the Snake River Trap. The release and return data used to calculate return rates come from Tables 2 and 5. The same caveats given for chinook are applicable to steelhead, as well.

Before continuing the reader may want to refer to Appendix 8 which shows the reieases by release site for chinook and steelhead and the return rates as of August 4, 1993. The main things to note are the relatively low return rates, the high degree of between year variability, and the lack of balance in the tagging levels between years and between release sites. The analysis that follows will aggregate over drainage so some of this detail will be lost.

4.1 Return rates and a binomial model

We will just examine the observed total return rates to Lower Granite of chinook and steelhead release groups. We define *total return* rate for a given release group as the ratio of all adult returns, regardless of *date* of return, to the number of fish originally released.

The number of fish that return are modeled as a binomial random variable. The essential assumptions are that the fish behave independently and have the same probability of experiencing any one particular fate, i.e., the fish are independent and identically distributed. The only two fates under consideration are either returning to Lower Granite Dam or not. Letting R denote an indicator variable for return, R is a Bernoulli random variable. Let $\Pr(R = 1) = p$. The objectives are to estimate the probabilities of return, p, for given release groups and to attempt to quantify possible differences in p's for different groups in terms of covariates.

Note that even if the larger set of more precisely specified fates was considered, such as returning in the kth year, so long as the fish behave independently and have identical probabilities for each fate, $\Pr(R = 1)$ is just the sum of probabilities for all fates that include return to Lower Granite Dam.

The maximum likelihood estimate of the return rate for a specific release group with n releases and x observed returns is simply $\hat{p} = \frac{x}{n}$.

Given the relatively low numbers returning, seen in previous tables, the Poisson approximation to the binomial should work quite well. I.e., the number of returns can be well approximated by a Poisson distribution with mean μ = np. We will use this fact to our advantage in the following section.

4.2 Generalized linear models

Estimated return rates will undoubtedly differ between different release groups. We would like to determine whether or not those differences can be ascribed to particular observable factors, e.g., some of the categories identified earlier in the report such as rearing type and geographic origin. We will use the methods of generalized linear models or GLMs (McCullagh and Nelder, 1989). The basic components of a GLM are a probability distribution in the exponential family of distributions (which includes binomial and Poisson models) and a function of the expected value of the random'variable, say $f(\mu)$, that can be modeled as a linear combination of covariates, $f(\mu) = \sum \beta_i x_i$. The function, f, is referred to as a link function.

We assume that the number of returns from a given release group can be modeled by the Poisson distribution with mean $\mu = np$ and that the logarithm of μ can be modeled as a linear combination of covariates, $\log(\mu) = X\beta$, where X is a matrix of covariates. Such a model will be referred to as a Poisson-log link GLM. Because our real interest is in p, not np, we will remove the influence of the release number by setting one of the covariates to be equal to the logarithm of n with corresponding coefficient β set equal to 1; i.e.,

$$\log(\mu) = \log(n) + \log(p)$$
$$= \log(n) + \beta_1 x_1 + \ldots \beta_r x_r$$

The use of a fixed coefficient in GLMs is known as including an offset.

For measuring the importance of different covariates, we look at deviance, which is the logarithm of the ratio of two likelihoods. In particular for a given model, M, the deviance is a function of the ratio of the likelihood for that model, L(M), to the likelihood of the full or saturated model, $L(Full)$, one for which there is a single parameter for every data point.

$$\text{Deviance(M)} = -2\log \frac{L(M)}{L(Full)}$$

For example, with the Poisson distribution the full model would use the observed counts, n_i, as estimates of μ_i, for each observation i. To compare different models, say $M1$ and $M2$, where $M1$ is a nested subset of $M2$, the change in deviance is what is of interest- does one model lead to a significant decrease in deviance relative to the other? The difference in the deviances is a likelihood ratio (LR) statistic:

$$LR = -2\log \frac{L(M1)}{L(M2)}$$

The χ^2 distribution, with degrees of freedom equalling the change in the number of parameters between models 1 and 2, is used as an approximation to the distribution of LR. With GLMs, such a test is referred to as a deviance test or more generally a likelihood ratio test. We will discuss the details of an alternative. test based on the change in deviances later.

4.3 Spring chinook results

Table 6 shows the estimated return rates for spring chinook release groups categorized by rearing type (hatchery or wild), Snake River drainage area, life stage, and migration year. The NAs represent categories for which there were no releases. As is clear from the low observed *total* return rates, partitioning returns by time of return, or at least year of return, would yield even sparser tables.

The most successful group was the 1991 Clearwater hatchery smolt releases, $\hat{p}$=0.00164 (4 returns from 2,439 releases). These fish were all raised at Dworshak hatchery and released downstream at the Clearwater trap.

Plots comparing the return rates are shown in Figure 1. Interactions may exist, but given that the return of a single additional fish from any of the groups could drastically change the estimates, it is practically impossible to determine if they do.

Confidence intervals for the contribution rates reveal the degree of overlap between the release groups. Figure 2 contains plots of the 95% confidence intervals for the 36 releases. The confidence intervals were calculated under the

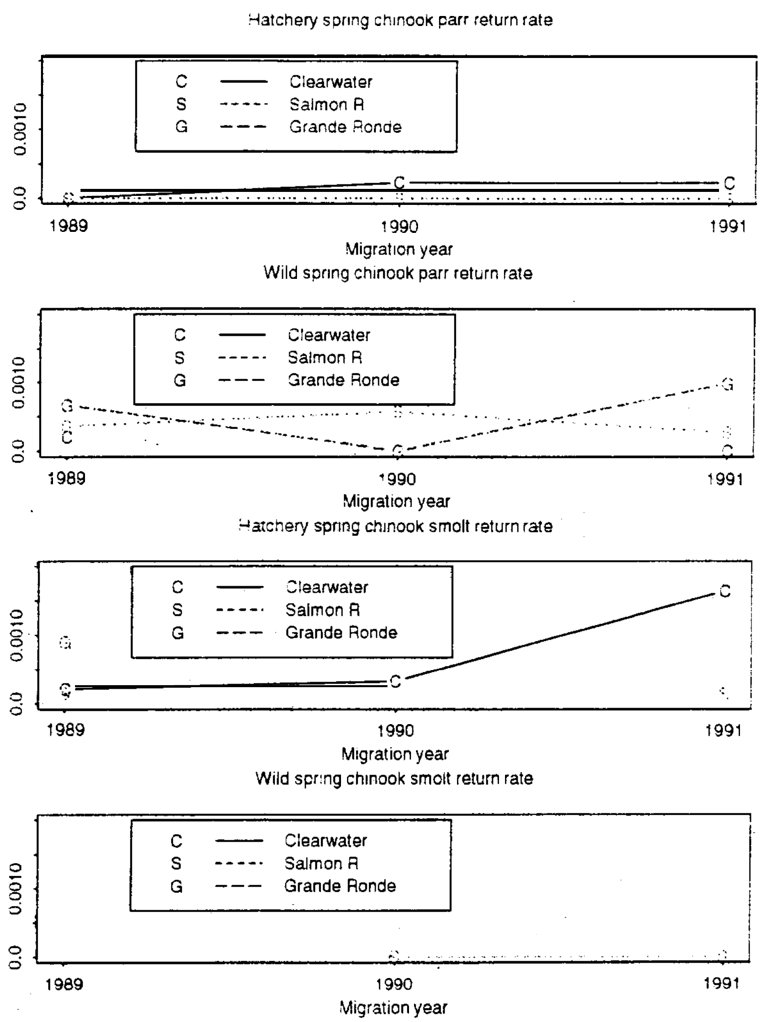

Figure 1: Spring chinook return rates for releases from 3 Snake River drainages

Table 4: Spring chinook return rates

RT	Drainage	Life Stage	MY 1989	MY 1990	MY 1991
H	Clearwater	Parr	0.000000	0.000226	0.000227
		Smolt	0.000213	0.000325	0.001640
	Salmon River	Parr	0.000000	0.000000	0.000000
		Smolt	0.000154	NA	0.000133
	Grande Ronde	Parr	NA	NA	NA
		Smolt	0.000898	NA	NA
W	Clearwater	Parr	0.000199	NA	0.000000
		Smolt	NA	0.000000	NA
	Salmon River	Parr	0.000359	0.000574	0.000269
		Smolt	NA	0.000000	0.000000
	Grande Ronde	Parr	0.000668	0.000000	0.000985
		Smolt	NA	NA	NA

binomial distribution. The upper confidence bound is the value of p for which the probability of observing x or fewer returns was ≤ 0.025. The lower confidence bound was determined analogously. Many of the wild release bounds extend beyond the displayed limits, largely because of very small release sizes. The point estimates are marked by x on the figure.

Four factors, life stage, rearing type, geographic origin, and migration year, were used as covariates in a Poisson-log link GLM for returns with release number as the offset. The statistical package S-Plus (Statistical Sciences, Inc.) was used to estimate the parameters via iterated weighted least squares (which can be shown to be equivalent to maximum likelihood estimates- see McCullagh and Nelder, 1989, pp 40-43). A sequence of main effects models was fit: a model with a single mean for all groups, means varying with life stage, with rearing type, with migration year, with geographic origin (Clearwater River, Salmon River, and Grande Ronde River drainages). Interactions may be significant, but because of missing values, many of the interactions could not be estimated. We decided, therefore, given the limitations of the data to not estimate coefficients for any interaction terms.

Before looking at the resulting estimates, two technical points should be discussed. The first point is that if one is at the model building stage, namely trying to determine which factors affect the return rate, the order in which variables are added to the model can affect p-values of tests of the significance of each variable. Suppose the p-values are based upon likelihood ratio tests (LRTs) of model 1 relative to model 2, where model 1 contains variable A only and model 2 contains variables A and B (a hierarchical model). Under the null hypothesis model 1 is assumed to be correct. However, the variables are in most cases not orthogonal to one another, i.e., the variation accounted for by one variable is not completely separate from the variation accounted for by another variable. So if variable A is added first, it may account for a certain amount of variation by itself and possibly be significant based on a LRT. On the

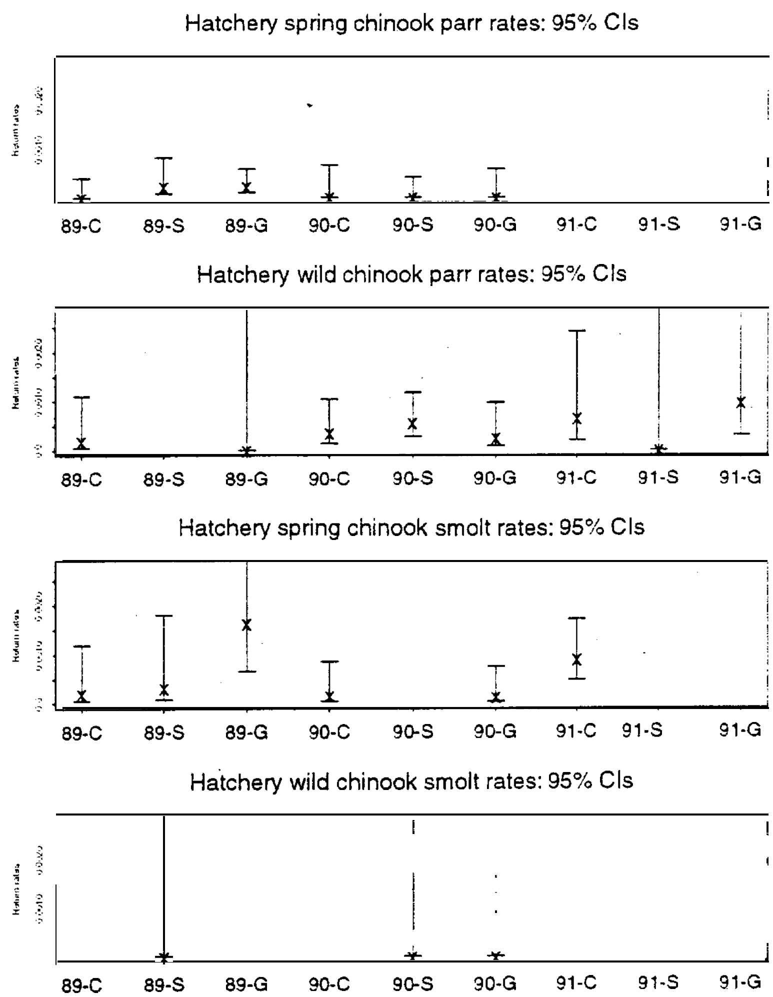

Figure 2: 95% confidence intervals for the spring chinook adult return rates.

other hand, if variable B is added first and then variable A, relative to a model with B included, A may no longer be statistically significant. Therefore, in the following analyses all possible orders of variable inclusion were considered.

A second technical point is that p-values based upon the chi-square approximation to the LRT (deviance test) can be very inaccurate, although they can provide a crude description of the relative importance of each factor. An alternative approach for calculating p-values thought to be more accurate (Skalski, et al., 1993) is to calculate an F-statistic:

$$F^* = \frac{(\Delta \text{Deviance } M_i)/(\Delta df_i)}{(\text{Deviance } M_{\max})/(df_{\max})}$$

where ΔDeviance M_i is the change'in deviance when going from the previous model to the ith model, M_i. Δdf_i is defined in an analogous manner and $M_{\max}$ is the largest model considered. The p-values calculated via F-tests will be included in the summary tables of the analysis of deviance and will be denoted p_F.

The parameter estimates and relative importance of each factor are shown in Table 7. Indicator variables for life stage (1 for parr, 0 for smolt), hatchery rearing type (1 for hatchery, 0 for wild), migration year 1989 and 1990 (0 for 1991), and regions Clearwater and Salmon (0 for Grande Ronde) were used to parametrize the factors. Negative parameter values mean that fish in that class are estimated to have lower return rates than fish with a category value not shown. For example, the parameter for the parr life stage is -1.52. All other categories being the same, a parr's probability of return is $e^{-1.52} \cdot$ 100% or about 22% of a smolt's probability of return. Similarly, a hatchery fish's return rate is about 21% of a wild fish's return rate. Migration year 1989 fish returned at lower rate than 1990 and 1991 fish, and 1991 fish returned at a lower rate than 1990 fish. Finally, the Grande Ronde River return rate was higher than both Clearwater River and Salmon River returns, and the Clearwater rate was higher than the Salmon.

The.deviance and change in deviance were calculated sequentially as the factors for life stage, rearing type, migration year, and geographic region were added. The model $M_{\max}$ in this case was the model with all 4 main effects included. which had a deviance of 15.62 and 16 degrees of freedom. An example of the deviance test is the comparison between the model (M_1) with life stage alone to the model (M_2) with life stage and rearing type. The change in deviance was 10.2 (36.85-26.65), the change in degrees of freedom was 1 (21-20), and the tail region above 10.2 of the χ^2 distribution with 1 degree of freedom is 0.0014.

Of the main effects all but migration year was found significant at the 5% level using the deviance test (likelihood ratio test). This was true for all possible orderings of inclusion of the main effects. Note that the p-values based on the deviance test and the F-statistic based p-values yielded reiatively similar results. Figure 3 contains plots of the deviance residuals versus the fitted values for the main effects model. A deviance residual, r_d, (McCullagh and Nelder, 1989) is

Table 7: ANODEV of spring chinook return rates

Variate	β	se(β)	z	p	Deviance	df	change	p	p_F
Intercept	-5.0383	0.6590	-7.65	0.0000	41.82	22			
Life stage	-1.5179	0.5025	-3.02	0.0025	36.86	21	5.0	0.0260	0.038
Rearing Type	-1.5384	0.5090	-3.02	0.0025	26.65	20	10.2	0.0014	0.005
Myear 89	-0.6022	0.4068	-1.48	0.1387					
Myear 90	0.2094	0.4296	0.49	0.6259	26.15	18	0.5	0.7798	0.777
Geog: Clw	-0.7815	0.4564	-1.71	0.0868					
Geog: Sal	-1.4634	0.4495	-3.26	0.0011	15.62	16	10.5	0.0052	0.016

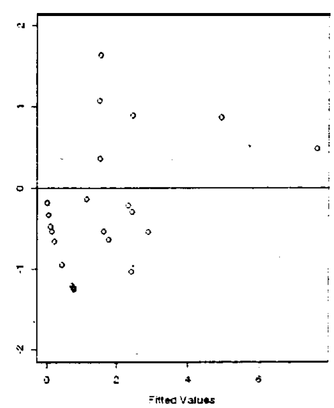

Figure 3: Deviance residuals versus fitted values for the main effect chinook model.

the square root of the deviance due to the observation, d, (the contribution to the likelihood ratio test statistic of the fitted versus a full model, a single parameter per observation) multiplied by the sign of the observed (y) minus expected (μ) difference,

$$r_d = \text{sign}(y - \mu)\sqrt{d}.$$

4.4 Summer steelhead results

A nearly identical analysis was carried out for summer steelhead returns. Table 8 reports the observed return rates categorized by rearing type, origin, and migration year. Figure 4 is a plot of the return rates and Figure 5 is a plot of

Table 8: Summer steelhead return rates

Rearing Type	Drainage	MY 1989	MY 1990
~~Hatchery~~	~~Clearwater~~	~~0.00534~~	~~0.00597~~
	Salmon River	0.00218	NA
	Snake Trap	0.00147	0.00720
Wild	Clearwater	0.00000	0.00212
	Salmon River	0.00112	NA‡
	Snake Trap	0.00334	0.00715

‡ Only 1 wild steelhead was released from the Salmon River for migration year 1990.

Table 9: ANODEV for summer steelhead return rates

Variate	β	se(β)	z	p	Deviance	df	change	p	p_F
Intercept	-5.2321	0.1960	-26.69	0.0000	44.28	9			
Rearing Type	0.3297	0.2143	1.54	0.1239	43.88	8	0.4	0.5292	0.763
MY 89	-0.6986	0.2197	-3.18	0.0015.	22.53	7	21.4	0.0000	0.067
Geog-Clw	-0.1634	0.2026	-0.81	0.4201					
Geog-Sal	-0.5557	0.3441	-1.61	0.1064	19.75	5	2.8	0.2492	0.718

the exact 95% confidence intervals for the return rates, where x marks the point estimates on the figure.

The GLM analysis is summarized in Table 9. Again because of lack of data and small sample sizes, only main effects were considered.

Determining the importance of the main effects is made more difficult because the order of inclusion of the variables makes a difference. If migration year is added before geographic origin, then geographic origin does not lead to a sizeable decrease in deviance. But if the order is reversed geographic origin and-migration year are both statistically significant using the deviance tests. A further complication is that the F-statistic based p-values are considerably different than the deviance test based values. The F-statistic based p-values never showed geographic origin to be important, but migration year was marginally significant in most orderings. In either case the migration year effect was the strongest main effect detected, with 1990 return rates higher than 1989 return rates on average. Table 8 indicates that this was definitely the case for the Snake Trap releases at least. Figure 6 contains a plot of the deviance residuals versus the fitted values.

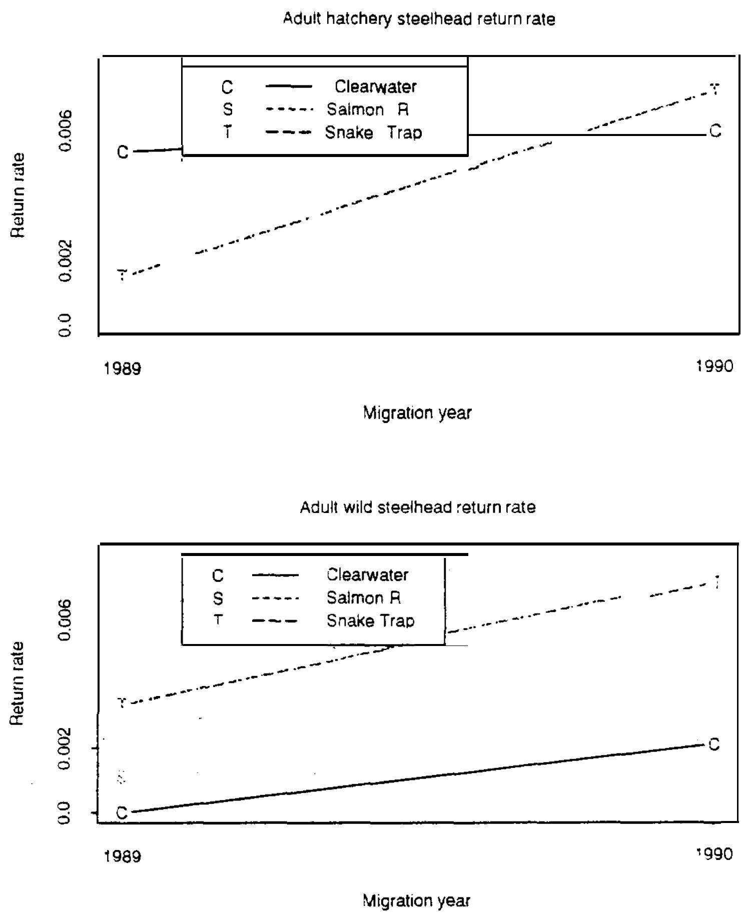

Figure 4: Summer steelhead return rates

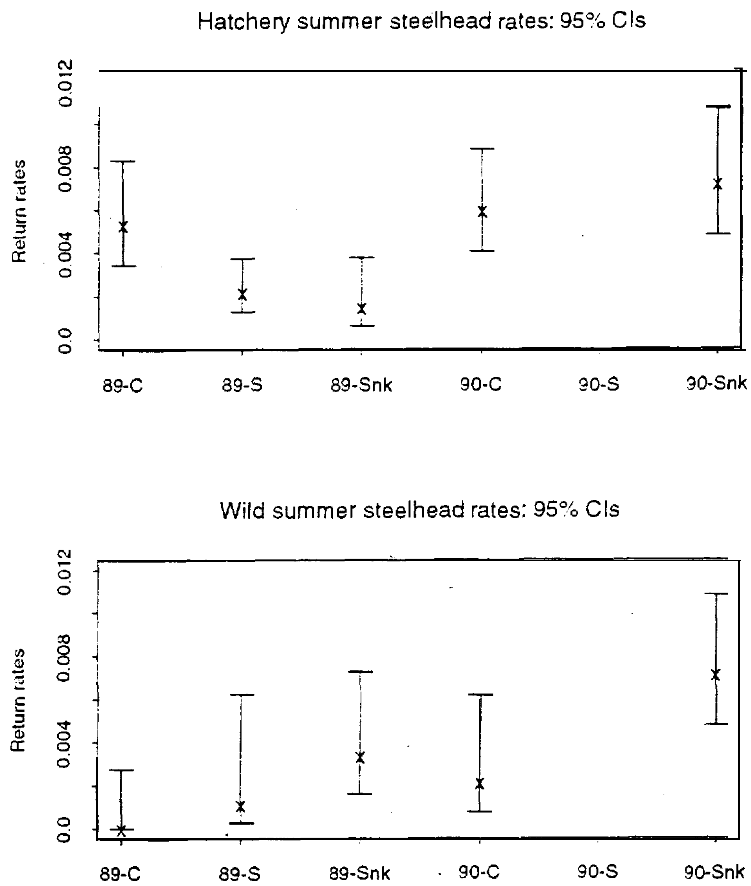

Figure 5: 95% confidence intervals for the summer steelhead adult return rates.

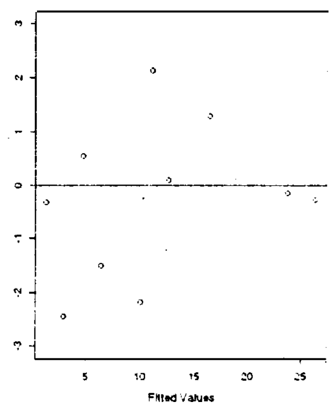

Figure 6: Deviance residuals versus fitted values for the main effect steelhead model.

5 Discussion

The analysis of the spring chinook and steelhead returns should be viewed more as a demonstration of one way of analyzing return rates than as a definitive statement about historical returns and influencing factors.

Interpretations of the analysis must be tempered for several reasons. First, more returns from the migration years examined are likely (indeed several more steelhead did return later in August, 1994), so the return data is incomplete. Second, the data analyzed were generated for a wide variety of purposes, including hatchery treatment studies (e.g., photoperiod studies of spring chinook at Dworshak'hatchery on the Clearwater Riverj as well testing fish passage detection facilities, so there are potentially confounding factors. Third, some adults return to Lower Granite Dam and are not detected, they either go through the navigation locks and somehow get through the adult bypass tubes undetected. Fourth, tag loss, although considered minor, is a possible problem. Fifth, the small number of years of information as well as gaps in the data, eg., a lack of Grande Ronde chinook releases for some years and a lack of Salmon River steelhead releases for the 1990 migration year, limits the scope of inference. Sixth, the fact that time of release was not accounted for, with the exception of the crude parr-smolt distinction for chinook, limits the accuracy of the inferences as weil. Observed differences from the return rates for coded-wire-tagged salmonids have raised questions about the accuracy of the estimated PIT-tagged return rates as well.

With these caveats in mind, we will make a few cautious observations. Spring chinook return rates for Snake River releases are very low overall. The best return (of detected fish) was about 16 of 10,000 tagged hatchery chinook smolts (Dworshak raised stock released at the Clearwater trap) survived the downstream migration, ocean migration, and return up the Columbia River to reach Lower Granite Dam. Summer steelhead return rates are roughly an order of magnitude higher, up to 7 out of 1,000 returned (Snake Trap wild releases).

For spring chinook potential interactions may exist between the factors considered and thus cloud the interpretation of main effects, but it appears that life stage, rearing type, and geographic origin may be important factors in return rates. Life stage effects would, of course, be expected given the overwintering mortality. The migration year effect did not appear strong for chinook based on the GLM analysis, but sample size limitations may be the reason.

The main feature of the steelhead returns is the apparent lack of consistency between years, drainages and rearing types. For example, the migration year 1990 returns appear to be more successful than the 1989 groups, but the magnitude of the difference varies considerably between the Clearwater and Snake Trap groups, for instance! and between the hatchery and wild stocks as well. GLM analysis did not indicate that these differences were statistically significant, however, but again small sample sizes and the many gaps in the data may be why.

There are many unanswered questions regarding the survival of Columbia River and Snake River salmonids. For instance, what is the difference in survival rates, at various life history stages, between juvenile salmon barged downriver versus those making the trip unassisted? PIT-tags and coded-wire-tags can both provide useful information regarding downstream survival, ocean survival and ocean harvest rates. Establishing additional adult detection facilities will increase the value of PIT-tags for answering such questions. Studies aimed particularly at estimating adult survival and return rates that have adequate sample sizes and broad geographic coverage will lead to more accurate answers, as well.

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7 Appendix A: Statistical Power Calculations

In this appendix we discuss procedures for calculating the power, as a function of sample size, against hypotheses concerning occurrence rates for relatively rare events. In other words, when the null hypothesis is wrong, we show how the probability of correctly rejecting the null hypothesis varies as the sample size changes. For the particular problem of comparing return rates for salmon experiencing different treatments, say, these procedures are aimed at determining the appropriate number of fish to tag to detect a treatment effect with a specified probability. A concrete example would be to test the effect of a drawdown of a reservoir behind a dam on the Columbia River on consequent adult return rates. The methods described herein are quite general, but to emphasize the case for salmon we will use the phrase *return rate* rather than occurrence *rate* and will denote it by p.

We will first consider the case of comparing a single control and a single treatment release, a paired design, where the p's for the control and treatment groups are *constant.* Under the null hypothesis, observations are assumed to arise from Binomial distributions with common return rate p, which is near to zero. The null and alternative hypotheses are stated as follows:

$$H_0 : p_1 \leq p_2 \quad (1)$$
$$H_a : p_1 > p_2 \equiv [p_1 = p_2 + \Delta], \quad (2)$$

. where $\Delta > 0$ and is assumed known for the purposes of calculation. We will designate $p_2 = p$ and refer to it as the base rate. As will become clear later statistical power will turn out to be a function of the base rate, A, and sample size. Note that two-sided tests can be dealt with similarly; in the case of using a z-test shown in the next section, the o-level is simply halved.

Next we will extend the solution to the case of replicate releases where p is random. In this case! p_i then follows some probability distribution with mean μ_{p_i} and the null hypothesis becomes

$$H_0 : \mu_{p_1} \leq \mu_{p_2} \quad (3)$$
$$H_a : \mu_{p_1} > \mu_{p_2} \equiv [\mu_{p_1} = \mu_{p_2} + \Delta,\ \Delta > 0] \quad (4)$$

Two scenarios will be considered for comparing two treatments when p is random. The first case will correspond to a paired, *controlled* experiment, where the experimental units,.say individual fish, are assigned at random to one of the two treatment groups. In the second case there are multiple replicate releases, possibly coming from different time periods and different geographic areas, among other things. This could be a model for observational studies where the experimental units cannot be readily assigned at random to one of two treatments and the experimental units are naturally grouped or blocked by some factor. An example is comparing salmon return rates between hatchery and wild stocks from several different-hatcheries and rivers over several years. The treatments are the hatchery and wild environments, but fish cannot be easily assigned to be a hatchery or wild fish. The natural grouping or blocking would be different hatcheries, river systems, and years.

7.1 Power calculations for a paired release with nonrandom p's

Power calculations for the null hypothesis in Equation 1, with nonrandom p are discussed here.

The power of a test depends upon the distribution generating the data and the test statistic. The observed data are the number of successes from a sample of size n, e.g., the number of previously tagged fish returning to Lower Granite Dam. For two samples of size n_1 and n_2, the number of successes x_1 and x_2 are by assumption distributed Binomial(n_1,p_1)and Binomial(n_2,p_2), respectively.

Several tests for equality of the rates are possible, including Fisher's exact test, F-tests from a logistic regression, deviance tests from a generalized linear model, and most simply a standard normal z-test. We will, for reasons of simplicity, base our calculations on a z-test. The resulting test statistic:

$$Z^* = \frac{\hat{p}_1 - \hat{p}_2}{\sqrt{(\frac{1}{n_1} + \frac{1}{n_2})\overline{p}(1-\overline{p})}}, \qquad (5)$$

where $\hat{p}_i = x_i/n_i$ and $\overline{p} = (x_1+x_2)/(n_1+n_2)$. We will reject the null hypothesis (1) if $|Z^*| \geq z_{1-\alpha}$, where $z_{1-\alpha}$ is the $1-\alpha$ quantile of a standard normal distribution. Our interest is in determining the probability $Z^* \geq z_{1-\alpha}$ if H_a (2) is true. For simplicity let $n_1 = n_2$.

The normal approximation can be used to calculate the statistical power of the test. Using the first few terms in a Taylor series expansion for Z^* as a function of x_1 and x_2, we find

$$\mathrm{E}(Z^*|H_a,p) \approx \frac{n\Delta}{\sqrt{k}} \qquad (6)$$

$$\begin{aligned}\mathrm{Var}(Z^*|H_a,p) &\approx n(p+\Delta)[k^{-1/2} - n\Delta/2k^{-3/2}(1-2p-\Delta)]^2 \qquad (7)\\ &+ np[k^{-1/2} + n\Delta/2k^{-3/2}(1-2p-\mathrm{A})]"\end{aligned}$$

where $k = n(2p + \Delta)(1 - \mathrm{p} - \mathrm{A}/2)$. The power is then

$$\Pr(Z^* \geq z_{1-\alpha}|H_a,p) \approx \Pr\left(Z \geq \frac{z_{1-\alpha} - \mathrm{E}(Z^*|H_a,p)}{\sqrt{\mathrm{Var}(Z^*|H_a,p)}}\right) \qquad (8)$$

$$= 1 - \Phi\left(\frac{z_{1-\alpha} - \mathrm{E}(Z^*|H_a,p)}{\sqrt{\mathrm{Var}(Z^*|H_a,p)}}\right) \qquad (9)$$

where Z is a Normal(O,l) random variable with cumulative distribution function Φ.

The accuracy of the above Taylor series approximatioris was assessed via simulations from Binomial distributions under H_a and was found to be fairly good. As an example, 20,000 experiments under H_a were simulated with the base rate p=0.0002 and Δ=0.0003. Table 10 compares the simulation experiment rejection rates to the approximate theoretical calculations.

Table 10: Comparison of simulated and approximate theoretical rejection rates under H_a with fixed p.

(p=0.0002, Δ=0.0003, α=0.05)

n	Simulation	Theoretical
5,000	19.7%	18.2%
10,000	30.7%	29.1%
15,000	44.7%	39.1%
20,000	51.9%	48.2%
25,000	59.2%	56.3%
30,000	65.8%	63.5%
35,000	71.0%	69.6%
40,000	74.0%	74.9%
45,000	78.6%	79.4%
50.000	82.6%	83.1%

From Equations 6 and 7 it is clear that power is a function of the significance level α, the underlying rate p, the difference in rates A, and the sample sizes. Two sample plots of the power against n are given in Figure 7. The top plot has p=0.0002 and the bottom plot has p=0.003; these values correspond to spring chinook and summer steelhead return rates, respectively, in the range of what was observed with the Snake River stocks. A varies from 0.0001 to 0.0003 in the first case and 0.001 to 0.003 in the second case; and the significance level, α, was set at 0.05 for a l-tailed test. Note that-the range of sample sizes shown for p=0.0002 is 1000 to 100,000 and 1000 to 50,000 for p=0.003. To determine the sample size per treatment group with these plots, one specifies the power and estimate of A and finds the corresponding point on the x-axis. For example, when p=0.0002 and A = 0.0003, to reject H_0 when H_a is true with 80% probability, a sample size of roughly 46,000 fish per treatment group is needed.

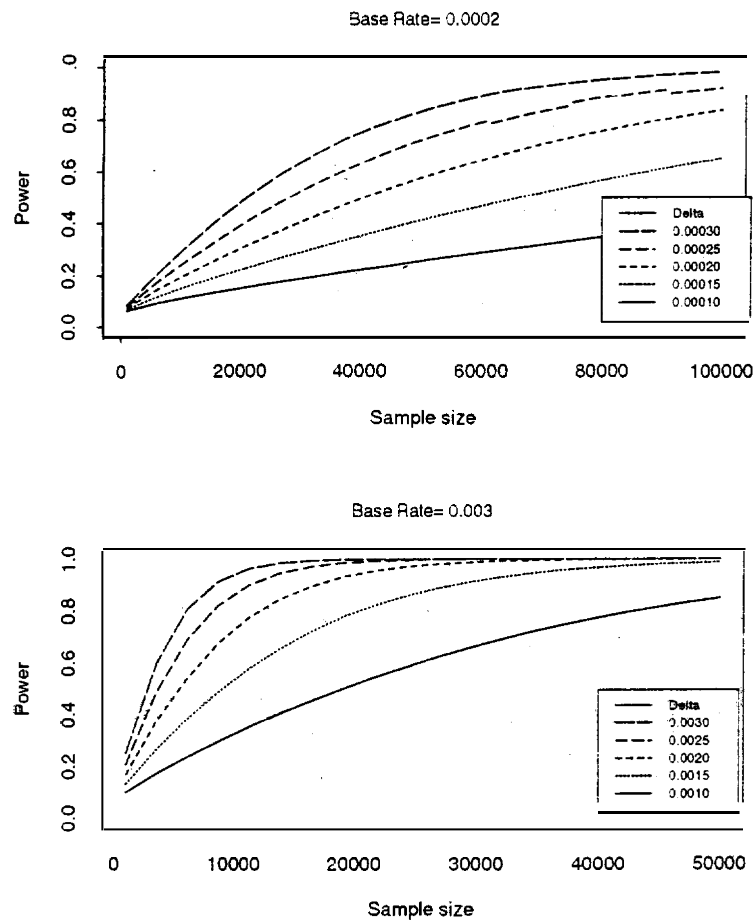
The example values were chosen to represent observed chinook and steelhead rates. If the chinook rate was thought to be less than 0.0002, for the same A values used in Figure 7, the power will be greater. Conversely, an increase in the baseline p means a decrease in power. For a more precise calculation of the power for any given p, A, and n, one should use Equation 9.

7.2 Power for replicated release studies with p random

When studies or experiments are conducted over a period of time, or range of space, say, the underlying return rate p may change over time or space. In this case view the rates as draws from some probability distribution D with mean μ_p and variance σ_p^2 ; i.e.,

$$p \sim D(\mu_p, \sigma_p^2), \quad 0 \leq p \leq 1, \tag{10}$$

Figure 7: Power against $H_o : p_1 \leq p_2$ when $p_1 = p_2 + \Delta$ (α=0.05)



where the distribution D may or may not be specified. In the case of two treatments, two distributions might be imagined,

$$p_i \sim D_i(\mu_{p_i}, \sigma^2_{p_i}),\ i = 1, 2. \tag{11}$$

The null hypothesis, stated previously in Equation 3, and the alternative hypothesis (Equation 4) are

$$H_0 : \mu_{p_1} \leq \mu_{p_2}$$
$$H_a : \mu_{p_1} > \mu_{p_2} \equiv [\mu_{p_1} = \mu_{p_2} + \Delta, \Delta > 0]$$

Two distinct scenarios will be considered when p is random, but in both cases the alternate hypothesis remains (4). In the first case a single p is assumed drawn from D. Conditional on that p, experimental units are assigned at random to one of two treatments. Units getting the first treatment are assumed to be Bernoulli($p + \Delta$), where $0 \leq p + \Delta \leq 1$ and units getting the second treatment are Bernoulli(p). An example of such an experiment would be comparing the survival rates for fish experiencing one of two hatchery treatments at a single hatchery, where fish are assigned at random to either treatment 1 or 2.

The test statistic could still be the z-statistic of Equation 5, but to calculate the power of the test under (4) the randomness in p needs to be taken into account. And, as is clear from previous calculations (Equation 9), if the rate p is random, then so is the power. One approach is to calculate the *expected* power in order to determine sample size. Letting $g(p)$ denote the probability distribution function for p, the expected power using the z-test statistic:

$$\mathrm{E}\left[\Pr(Z^* \geq z_{1-\alpha}|H_a)\right] \approx \int 1 - \Phi\left(\frac{z_{1-\alpha} - \mathrm{E}(Z^*|H_a, p)}{\sqrt{\mathrm{Var}(Z^*|H_a, p)}}\right) g(p)\mathrm{d}p \tag{12}$$

In the second case several draws, $R_1 + R_2$, from the distribution for p are made. For R_1 of the draws. treatment 1 occurs and the remaining R_2 get treatment 2. The realizations are denoted $p_{i,j}$ for treatment i and replicate j, $j = 1, \ldots, R_i$. Correspondingly $n_{i,j}$ experimental units are assigned to treatment i and replicate j. Under H_a the experimental units getting treatment 1 are Bernoulli$(p_{1,j} + \Delta)$.

In this case a different test statistic is used in order to basd inference on all replicates. A natural statistic is the t-statistic,

$$t^* = \frac{\bar{\hat{p}}_1 - \bar{\hat{p}}_2}{\sqrt{\widehat{\mathrm{Var}}(\bar{\hat{p}}_1 - \bar{\hat{p}}_2)}}, \tag{13}$$

where

$$\begin{aligned}\mathrm{Var}(\bar{\hat{p}}_1) &= \mathrm{E}_1\mathrm{Var}_{2|1}(\bar{\hat{p}}_1) + \mathrm{Var}_1\mathrm{E}_{2|1}(\bar{\hat{p}}_1) \\ &= \mathrm{E}_1\frac{1}{R_1^2}\sum_{j}^{R_1}\frac{p_{1,j}(1-p_{1,j})}{n_{1,j}} + \mathrm{Var}_1\frac{1}{R_1}\sum_{j=1}^{R_1}p_{1,j}\end{aligned} \tag{14}$$

$$= \frac{\mu_{p_1} - \sigma^2_{p_1} - \mu^2_{p_1}}{R_1^2} \sum_j^{R_1} \frac{1}{n_{1,j}} + \frac{\sigma^2_{p_1}}{R_1}$$

The critical region for testing $H_0 : \mu_{p_1} = \mu_{p_2}$ is $t^* > t_c$, where $t_c = t_{1-\alpha, R_1+R_2-2}$, the $(1 - \alpha)$ quantile for the t-distribution with $(R_1 + R_2 - 2)$ degrees of freedom.

The power for H_a with this test statistic can be calculated from the non-central t-distribution. In other words, under H_a,

$$\Pr(t^* > t_{1-\alpha,k} | H_a) = 1 - T_{k,\delta}(t_{1-\alpha,k}) \tag{15}$$

where $T_{k,\delta}$ denotes the cumulative distribution function for a non-central t-distribution with $k = R_1 + R_2 - 2$ degrees of freedom and non-centrality parameter,

$$\delta = \frac{\Delta}{\sqrt{\mathrm{Var}(\bar{\hat{p}}_1) + \mathrm{Var}(\bar{\hat{p}}_2)}} \tag{16}$$

Power is not random in this case; the randomness in p has been accounted for by using the t-distribution. Power depends simply upon the mean μ_p and the variance σ^2_p of the distribution D as they enter in the non-centrality parameter.

A second point to make is that there are now two sample sizes to consider, the number of replications R and the number of experimental units in a given replication, n. For example, returning to the hatchery-wild- comparison, the question would be how many years to gather information (the number of replications) and how many fish to monitor (tag) each year.

We now consider two approaches to calculating the power, and consequently sample size, using historical information. The first approach is a non-parametric procedure which relies upon only the first and second moments of the distribution for p. The second approach is an empirical Bayes method for which a family of distributions for p is specified, but the historical data is used to estimate the parameters indexing the particular member of the family.

7.2.1 A distribution free solution

Suppose that one has historical information, say a sequence of experiments, with observed values $x_1, \ldots, x_N$, and corresponding estimates of return rates $\hat{p}_1, \cdot\ , \hat{p}_N$, all arising from the null distribution. For the single p, controlled experiment situation, the simplest tack to take is to use the mean of the estimates, $\bar{\hat{p}}$ = l/N $\sum_{i=1}^{N} \hat{p}_i$, as the mean of the distribution, namely μ_p, and substitute $\bar{\hat{p}}$ for p in the expectation and variance of Z^* in Equations 6 and 7. This serves as a first order.approximation to $\mathrm{E}(Z^*)$; further terms could be used to refine the approximation.

For the multiplep t-test situation, the non-centrality parameter, 6 (Equation 16), needs to be estimated. The variance of $\bar{\hat{p}}$ can be estimated using the sample mean $\bar{p}$ as an estimate of μ_p and σ_p^2 can be estimated using the sample variance of the $\hat{p}_i$s:

$$\hat{\sigma_p^2} = \frac{\sum_{i=1}^{N}(\hat{p}_i - \bar{p})^2}{N-1} \tag{17}$$

For a given Δ, μ_{p_1} must be incremented by Δ in the variance calculation (Equation 15). An example of the calculation of power as a function of R and n will be given later, where an alternative approach to estimating μ_p and σ_p^2 is given, but the power calculations will be the same as here.

7.2.2 **Parametric empirical Bayes solution**

Given full knowledge of the distribution of p, one can calculate the expected power for the single p case using Equation 12 or the power for the multiple p's case using Equation 15. In the case of a single p, the integral in 12, would need to be calculated. In the case of multiple p, one would simply have to calculate the mean and variance of the distribution g and calculate the power under the non-central t-distribution.

The problem, of course, is that g(p) will likely be unknown. However, one might have theoretical arguments for specifying at least the *family* of distributions to which g belongs, indexed by some parameter θ, say, $g(p|\theta)$, where θ will be referred to as a hyperparameter.

The historical information described previously, $x_1, \ldots, x_N$, can be used in this case to estimate the unknown hyperparameter θ. The solution to the estimation of a parametrized version of $g(p)$ is known as parametric empirical Bayes. The main idea is to express the likelihood for θ in terms of the observed data x rather than p. The formulation is as follows,

$$L(\theta|x) = \prod_{i=1}^{n} \int_p f(x_i|p)g(p|\theta)dp \tag{18}$$

Maximize (18) with respect to θ to get $\hat{\theta}$. Then calculate expected power as before but using $\hat{\theta}$. For example, in the single p case, Equation 12 becomes

$$E\left[\Pr(Z^* \geq z_{1-\alpha}|H_a)\right] = \int_r 1 - \Phi\left(\frac{z_{1-\alpha} - E(Z^*|H_a, p)}{\sqrt{Var(Z^*|H_a, p)}}\right) g(p|\hat{\theta})dp \tag{19}$$

For the multiple p case, calculate $E(p|\hat{\theta})$ and $Var(p|\hat{\theta})$ and use the estimates to compute $Var(\bar{p})$, the non-centrality parameter, 6, and subsequently the power.

7.2.3 Beta-Binomial case

As an application of the parametric empirical Bayes method, we consider the problem of determining the necessary number of fish to tag to attain a desired power level. Let the distribution of surviving fish be Binomial with known release number N and unknown survival rate p. Assume that the survival rate p is a random variable that varies between years and follows a Beta distribution with parameters α, β. Suppose that N experiments have been conducted in the past, so $(x_1, n_1), \ldots, (x_N, n_N)$ is the historical data.

The likelihood with respect to the hyperparameters is

$$\begin{aligned} L(\alpha,\beta|\mathbf{x}) &= \prod_{i=1}^{N} \int_p \binom{n_i}{x_i} p^{x_i}(1-p)^{n_i-x_i} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} p^{\alpha-1}(1-p)^{\beta-1} dp \quad (20) \\ &= \prod_{i=1}^{N} \binom{n_i}{x_i} \int_p \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} p^{x_i+\alpha-1}(1-p)^{n_i-x_i+\beta-1} dp \quad (21) \\ &= \prod_{i=1}^{N} \binom{n_i}{x_i} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \frac{\Gamma(\alpha+x_i)\Gamma(\beta+n_i-x_i)}{\Gamma(\alpha+\beta+n_i)} \quad (22) \end{aligned}$$

This distribution with respect to a single x_i is a Beta-Binomial. For simplicity let $\alpha=1$. This is reasonable when p is relatively small, which is certainly the case with salmon return rates. The likelihood then simplifies, using $\Gamma(1+y) = y\Gamma(y)$, to

$$L(\beta|\mathbf{x}) = \beta^N \prod_{i=1}^{N} \frac{n_i!}{(n_i-x_i)!} \frac{\Gamma(\beta+n_i-x_i)}{\Gamma(1+\beta+n_i)}. \quad (23)$$

The above likelihood equation can be maximized with respect to β fairly easily (e.g., the *nlmin* function in S-Plus (Statistical Science, Seattle, WA) works well) to yield $\hat{\beta}$.

7.2.4 Example

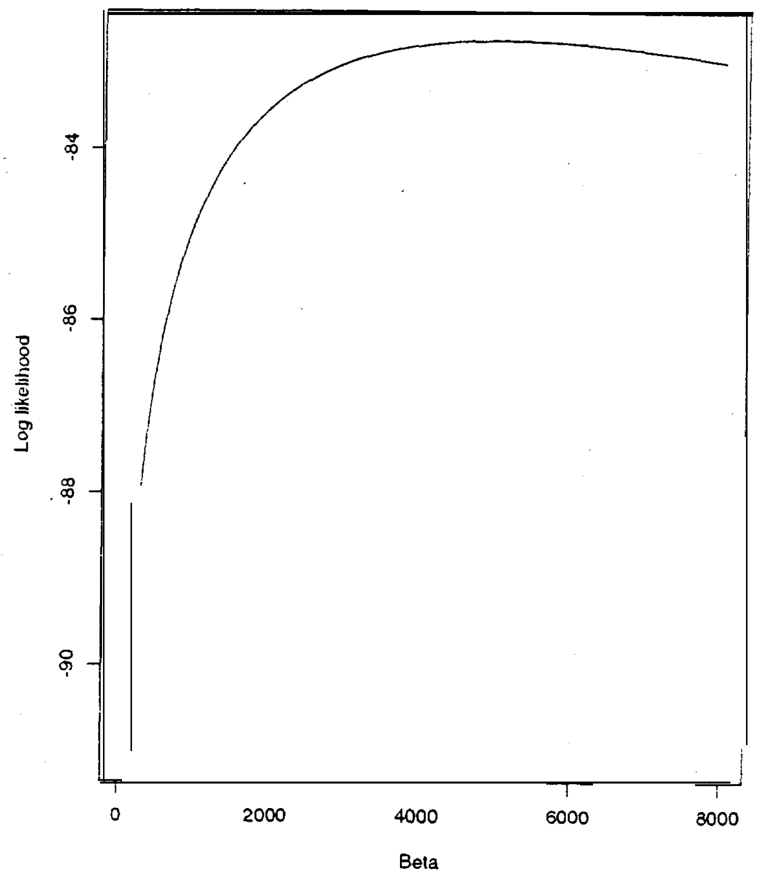
Using the special case of the Beta-Binomial distribution, we present an example of the parametric empirical Bayes method as applied to power calculation. One can think of the return of tagged fish as the data. Suppose we have 3 years of historical returns. The returns (successes), x, and sample sizes n are (2 of 9000), (2 of 12000), and (4 of 19000).

The likelihood (23) is maximized with these 3 data points to yield the MLE $\hat{\beta} = 4933.9$. A plot of the log likelihood is given in Figure 8. The expected return rate is $\frac{1}{1+\hat{\beta}} = 0.000203$. The simple average of the observed rates is 0.000200.

To calculate the expected power for the single p case, we need to calculate the integral in Equation 12. An analytical solution would be difficult; this is actually a double integral because of the normal cumulative distribution function Φ. Using Splus we can solve this using a mixture of numerical methods (quadrature) and Monte Carlo integration. The integral Φ will be computed using Splus's (numerically calculated) function *pnorm*. For the outer integral we will generate random samples, $p_1^*, \ldots, p_M^*$, from the distribution $g(p)$, i.e., the Beta(1, $\hat{\beta}$) distribution. The integral is then estimated by

$$\frac{1}{M} \sum_{i=1}^{M} \left[1 - \Phi\left(\frac{z_{1-\alpha} - E(Z_i^*|H_a, p_i)}{\sqrt{\mathrm{Var}(Z_i^*|H_a, p_i)}} \right) \right] \quad (24)$$

Figure 8: Log-likelihood of β for Beta-Binomial based on 3 data points



Two plots of the (estimated) expected power versus sample size n are shown in Figure 9. The top figure represents a spring chinook release and provides a comparison with the top plot in Figure 7 where the baseline rate p is 0.0002, but p is not random. 9. The power when p is random is slightly higher than when p is fixed for some levels of n and il. This is likely due to the skewness of the particular Beta distribution. When p is less than 0.9002, the power is higher. Because the distribution for p is skewed to the right, the probability of values less than the mean value, namely less than 0.0002, is greater than 0.5. Therefore more than half the generated values of p will be less than 0.0002, on average, and·the power will be greater. The bottom plot in Figure 7 presents an analogous case for a summer steelhead release ($E(p)=0.003$).

For the multiple p case, using the t-test, the expected value and variance of the parameter p are needed. The PEB estimates from above are $\frac{1}{1+\hat{\beta}}$ = 0.000203 and $\frac{\hat{\beta}}{(2+\hat{\beta})(1+\hat{\beta})^2} = 4.10e\text{-}8$, for the mean and variance,respectively. The calculation of the power requires the numerical integration of the non-central t-distribution. A convenient normal approximation given by Abramowitz and Stegun (Handbook of Mathematical Functions, 1970) is the following.

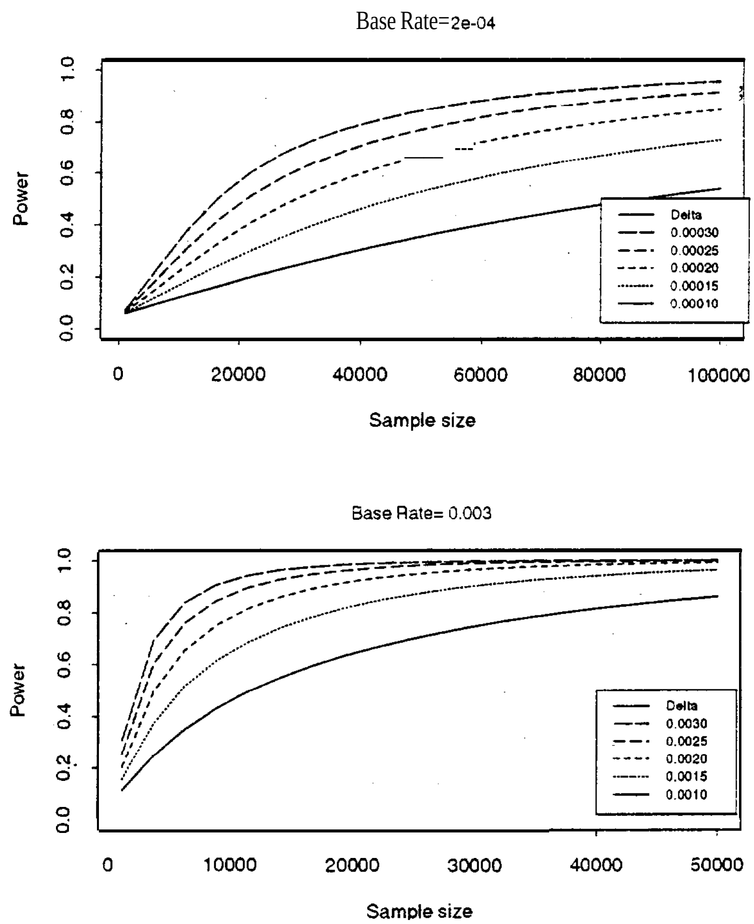
$$\Pr(t > t_{k,1-\alpha}) \approx 1 - \Phi\left(\frac{t_{k,1-\alpha}(1 - \frac{1}{4k}) - \delta}{\sqrt{1 + \frac{t^2_{1-\alpha}}{2k}}}\right), \tag{25}$$

where k is the degrees of freedom. This approximation improves as the degrees of freedom increases.

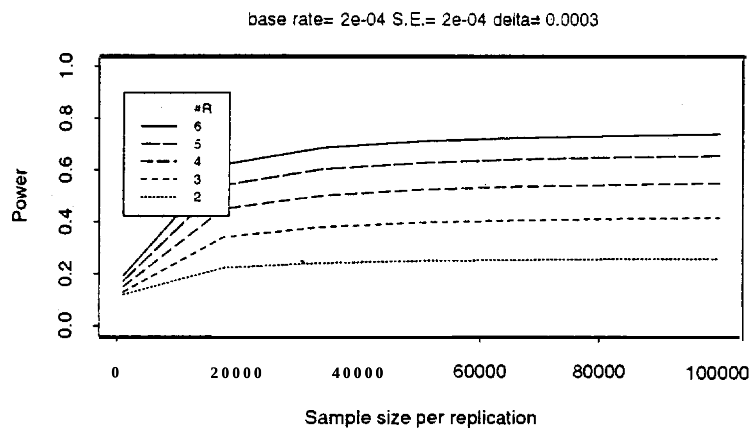
Two examples of the relationship between power, number of replications and sample size per replication are given in Figure 10. The top figure is based on the same $\hat{\beta}$ given above yielding $E(p)=0.000203$, similar to ipring chinook return rates. The second figure assumes that $\hat{\beta}$ equals 333, yielding $E(p)=0.003$ and $V(p)=8.91e\text{-}6$, mimicking steelhead return rates.

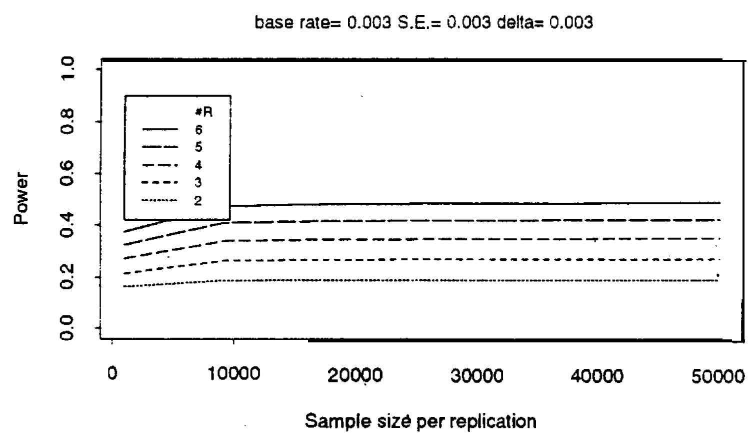
Note that the independent replicates, multiple p case requires a larger sample to achieve a particular power than the single p, paired data case; compare Figure 7 to Figure 10. This is due to the additional between replicate variation in the former case, simply a reflection of the advantage of doing a controlled experiment with blocking. Also note that the·maximum power attainable is less than 1 for even 6 replicates per treatment, no matter how many samples per replicate. Again this is due to the between replicate variation. Increasing the number of replicates is the best solution.

Figure 9: Expected power for paired design



, Figure 10: Power curves based on tests with multiple p





8 Appendix B. Detailed listing of chinook and steelhead releases

The counts of juvenile releases was retrieved from PTAGIS2 by generating 'Tagging Details Report' using the *sum_tag_by_srrt_rel_site* format. The queries were generated per drainage using two separate passes through the data pass. On one pass selections were made on the basis of tagging site and on another pass release site was used. This helped to capture release groups which had information missing from one of these fields. A third pass on the basis of river kilometer was sometimes made, but this field tends to be empty more frequently than the other two.

The tagging sites/release sites were identified by using PIT Tag Specification Report prepared by the PIT Tag Steering Committee. All the Grande Ronde sites were identified by having river kilometer values beginning with 522.271 (522 miles from the Pacific Ocean to the Snake River confluence and then 271 kilometers to the Grande Ronde River confluence). For the Clearwater River it was 522.224 and for the Salmon River it was 522.303.

The resulting release numbers partitioned by release site are listed in Tables 11 and 12. The latter 3 columns of each table are the percent return rates through August 4, 1993; i.e., #returns/#released*100.

Table 11: Spring chinook release numbers and % return rates

Drainage	RT	Site	MY 1989	MY 1990	MY 1991	% 1989	% 1990	% 1991
Clearwater	H	Dwor	14,212	11,934	11,262	0.007	0,025	0.009
		Clwtrp	0	0	3,992	NA	NA	0.100
		Crookr	0	0	801	NA	NA	0
		Crotrp	0	0	12	NA	NA	0
		Koos	0	0	2,427	NA	NA	0.124
		Powp	0	0	801	NA	NA	0
		Rcdp	0	0	800	NA	NA	0
Salmon	H	Alc	300	0	0	0	NA	NA
		Salr	336	0	0	0	NA	NA
		Salrsf	0	0	400	NA	NA	0
		Sawt	12,183	9,121	13,508	0.008	NA	0.007
Grande Ronde	H	Looh	10.017	0	0	0.090	NA	NA
Clearwater	W	Crookr	2,472	31	747	0	0	0
		Redr	2,559	0	0	0.039	NA	NA
		Crotrp	0	0	425	NA	NA	0
Salmon	W	Altura	410	1,043	407	0	0	0.246
		Frencc	310	0	202	0	NA	0
		Polec	260	0	209	0	NA	0
		Sslr	2,523	30	249	0.040	0	0
		s alref	7 4 5	0	533	0	NA	0
		Salrsf	0	0	992	0	NA	0.101
		Sawtrp	1,762	0	1,444	0.114	NA	0
		Smilec	106	0	3	0	NA	0
		Valeyc	2,248	2,512	1.031	0.044	0.040	0
		Bearvc	‘0	1,557	353	NA	0.064	0
		Bigc	0	2,035	726	NA	0.049	0
		Marshc	0	2,517	861	NA	0.119	0
		Sulfuc	0	2,515	0	NA	0.040	NA
		Elkc	0	16	247	NA	0	0
		Capehc	0	0	164	NA	NA	0
		Hucklc	0	0	5	NA	N.4	0
		Redflc	0	0	12	NA	NA	0
Grande Ronde	W	Grandr	2,993	0	0	0.067	NA	NA
		Cathec	0	0	1,013	N.4	NA	0.099
		Lostir	0	84	1,017	NA	0	0.098

Table 12: Summer steelhead release numbers and % return rates

Drainage	RT &	Site	MY 1989	MY 1990	MY 1991	% 1989	% 1990	% 1991
Clearwater	H	Clwtrp	562	1236	1275	0.178	0.243	0
		Dwor	2999	2945	3000	0.600	0.747	0.100
		Crookr	0	4	2	NA	0	0
		crotrp	0	0	2	NA	NA	0
Salmon	H	Lsalr	3058	0	2101	0.327	NA	0.571
		Sawt	2906	0	1924	0.103	NA	0.364
		Pahsir	0	0	500	NA	NA	1.400
		Salref	0	0	1500	NA	NA	0.133
		Salrnf	0	0	500	NA	NA	1.000
Snake Trap	H	Snktrp	2725	3193	2692	0.147	0.720	0.111
Clearwater	W	Clwtrp	103	1310	776	0	0.229	0.387
		Crookr	1047	107	555	0	0	0
		Redr	1	0	0	0	NA	NA
		crotrp	0	0	339	NA	NA	0
		Relief	177	0	0	0	NA	NA
Salmon	W	Frencc	45	0	0	0	NA	NA
		Polec	85	0	0	0	NA	NA
		Salr	382	0	0	0.262	NA	NA
		Sawtrp	304	0	54	0	NA	0
		Smilec	45	0	0	0	NA	NA
		Sulfuc	0	1	0	NA	0	NA
		Altura	32	0	0	0	NA	NA
Snake Trap		Snktrp	1794	3079	3628	0.334	0.715	0.276

9 Appendix C. Detailed listing of adult chinook returns

All chinook returns as of August 4, 1993 to Lower Granite Dam are listed in Tables 13 and 14. [1] Geographic area is classified by drainages of the Snake River, Clearwater, Salmon, and Grande Ronde along with Snake mainstem. The sole remaining Lower Granite return that did not fall into one of these classes is designated other (a release from Port Kelly).

The abbreviations for geographic origin are Clw (Clearwater drainage), Grd (Grande Ronde drainage), Snk (Snake mainstem), Sal (Salmon drainage), and Col (Columbia River). The release site codes can be found in the PSFMC's PIT Tag Specification Document.

The run-rearing type (R-RT) abbreviations are Sp, Su, F, and Unknown for spring, summer, fall and unknown, respectively, and H, W, and U for hatchery, wild, and unknown, respectively.

[1] Data omission, not discovered until after August 4, 1993, led to an omission of 13 spring chinook returns. Eleven chinook adults (1988 brood) from the Dworshak National Fish Hatchery and two chinook adults from the Snake River trap were mis-identified as mortalities in PTAGIS2 and have not been included in the summary table.

Table 13: Spring Chinook returns to Lower Granite Dam

R-RT‡	MY	Geog	R Site	R Date	Tag ID	Tag Group	Obs Date	Age
Sp-H	87	Clw	CLW	4/03/87	7F7E244560	IDFGa7.0403	5/08/89	4
	l - u -	Clw	CLW	4/09/87	7F7E244811	IDFGa7.0409	5/11/89	4
	8 9	Clw	DWOR	3/28/89	7F7E617343	KER88315.T4A	9/24/91	3
	89	Sal	SAWT	3/15/89	7F7E400E51	TC89006.SAW	6/30/90	5
	a9	Grd	LOOH	4/02/89	7F7E650937	KER89046.LH1	4/30/92	5
	a9	Grd	LOOH	2/16/89	7F7E3F6568	KER89047.LH1	4/11/92	5
	a9	Grd	LOOH	2/16/89	7F7E3F6011	KER89047.LH2	5/23/92	4
	a9	Grd	LOOH	2/16/89	7F7E45403D	KER89047.LH2	7/02/91	4
	89	Grd	LOOH	2/16/89	7F7E574D45	KER89047.LH2	5/24/91	4
	89	Grd	LOOH	2/16/89	7F7E6C2845	KER89047.LH2	5/28/92	5
	a9	Grd	LOOH	2/16/89	7F7E6C3203	KER89047.LH2	5/26/91	4
	a9	Grd	LOOH	2/16/89	7F7E70640F	KER89047.LH2	5/08/92	5
	89	Grd	LOOH	2/15/89	7F7E3F613B	SA89046.LH1	6/14/91	4
	90	Clw	DWOR	12/16/89	7F7F144C79	LAK89340.DL3	5/15/92	4
	90	Clw	DWOR	3/27/90	7F7F080344	CSM90086.YA2	5/18/92	4
	90	Clw	DWOR	3/27/90	7F7F2D1828	CSM90086.YA2	6/10/93	5
	91	Clw	DWOR	4/04/91	7F7F5E3E6D	WDM900323.B26	5/09/93	4
	91	Clw	CLWTRP	10/2/90	7F7F3C2C0F	WPC90268.DW4	5/12/93	4
	91	Clw	CLWTRP	10/9/90	7F7F3C365A	WPC90267.DW3	5/22/93	4
	91	Clw	CLWTRP	10/9/90	7F7F3C3A09	WPC90267.DW3	6/02/93	4
	91	Clw	CLWTRP	10/9/90	7F7F3D0A2F	WPC90268.DW4	6/02/93	4
	91	Clw	KOOS	4/16/91	7F7D050143	WDM91064.AY1	5/25/93	4
	91	Clw	KOOS	4/16/91	7F7E432067	WDM91064.AY1	5/29/93	4
	91	Clw	KOOS	4/16/91	7F7F0A5973	WDM91064.AY1	6/16/93	4
	91	Sal	SAWT	3/08/91	7F7F58422D	DAC900293.S8B	6/04/93	5
Sp-W	88	Sal	SALR	9/11/87	7F7E227C68	SR87254.4BT	5/14/91	4
	88	Sal	SALR	9/17/87	7F7E26117D	SR87260.4BT	6/20/90	3
	88	Sal	SALR	4/14/88	7F7E233C52	SR88106.1ST	6/14/91	4
	89	Clw	REDR	8/06/88	7F7E2F647C	CSM88220.RR1	5/11/92	4
	a9	Sal	SAWTRP	9/26/88	7F7E322F75	SWT270	6/09/91	4
	a9	Sal	VALEY C	8/21/88	7F7E426252	CSM88234.VC1	5/14/91	4
	a9	Sal	SALR	8/15/88	7F7E432067	CSM88229.SR1	5/29/93	6
	a9	Grd	GRANDR	9/19/88	7F7E331165	KER88264.GR1	5/17/92	5
	a9	Grd	GRANDR	9/20/88	7F7E24212F	KER88265.GR1	4/19/92	5
	90	Sal	MARSHC	8/12/89	7F7F185A68	KMC89224.MC1	5/14/92	4
	90	Sal	MARSHC	8/13/89	7F7F14612F	KMC89225.MC1	5/08/92	4
	90	Sal	MARSHC	8/13/89	7F7F157B16	KMC89225.MC1	5/08/92	4
	90	Sal	SULFUC	8/09/89	7F7F145223	OWJ89221.SU2	5/10/92	4
	90	Sal	VALEYC	8/18/89	7F7F182A12	KMC89230.VC2	5/14/93	5
	90	Sal	BEARVC	8/16/89	7F7F163670	SA89228.BV2	6/05/93	5
	90	Sal	BIGC	8/24/89	7F7F11391D	SA89235.BC3	5 26 93	5
	91	Sal	ALTULC	8/22/90	7F7F775637	RBK90233.AC1	5/15/93	4
	91	Sal	SALRSF	8/19/90	7F7D00332D	SA90231.SF2	6/11/93	4
	91	Grd	CATHEC	9/21/90	7F7F752512	SA90263.CC2	5/13/93	4
	91	Grd	LOSTIR	9/19/90	7F7F5F6C0F	SA90261.LR1	7/11/93	4
Sp-u	88	?	SW+CH?	4/21/88?	7F7E330918	AEB88112.PS	7/05/91	5
	88	Snk	SNKTRP	4/18/88	7F7E242D48	EWB88109.SNK	5/15/90	4
	89	Sal	SAWT	4/11/89	7F7E406368	RBK89101.SIT	6/28/91	4
	a9	Sal	SAWT	4/18/89	7F7E420B55	RBK89108.SWT	5/27/91	4
	a9	Col	PKELLY	5/07/89	7F7F08660C	KER89126.BN1	9/30/91	4
	90	Clw	[redacted]DKR	3/21/[redacted]	7F7E052E[redacted]	[redacted]BK90080.CRT	5/13/93[redacted]	5
	90	Clw	CROOKR	10/21/89	7F7F0A7A20	RBK89294.CRT	5/21/93	5
	90	Sal	SALR	4/07/90	7F7F364A51	RBK90097.S WT	5/18/93	5
	90	Sal	SALR	10/11/89	7F7E560672	RBK89284.SWT	6/03/93	5
	90	Sal	SALR	3/16/90	7F7F085601	RBK90075.SWT	5/30/93	5
	90	Sal	SMILEC	8/19/89	7F7F0A1701	RBK89231.SR1	6/07/93	5
	90	Sal	SALR	5/14/90	7F7F361228	RBK90134.SWT	6/24/93	5

‡ R-RT=race-rearing type, MY=migration year, R Site=release site,

Table 14: Summer, Fall! and Unknown Chinook returns to Lower Granite Dam

R-RT‡	MY	Geog	R Site	R Date	ID	Grp	Obs Date	Age
Su-W	89	Sal	SECESH	8/24/88	7F7E2F682A	CWM88237.SE1	6/20/91	4
	a9	Sal	SECESH	8/24/88	7F7E427816	SA88237.SE1	7/01/91	4
	90	Sal	SECESH	8/28/89	7373157264	SA89240.SE2	6/19/92	4
F-W	91	Snk	SNAKER	6/13/91	7F7D1D5A36	WPC91164.G29	10/29/92	
U-U	89	Snk	SNKTRP	4/06/89	7F7E3E1D0A	EWB89096.SNK	6/02/92	5
	90	Clw	CLWTRP	5/06/90	7F7F372158	EWB90126.CLW	5/08/93	5
	90	Clw	CLWTRP	5/23/90	7F7F426243	EWB90143.CLW	5/08/93	5
	90	Clw	CLWTRP	5/18/90	7F7F3D4B7E	EWB90138.CLW	6/01/93	5
	90	Snk	SNKTRP	4/10/90	7F7E651976	EWB90100.SNK	5/01/92	4
	90	Snk	SNKTRP	4/18/90	7F7F431A0E	EWB90108.SNK	6/16/92	4
	90	Snk	SNKTRP	4/21/90	7F7E5 1652 1	EWB90111.SNK	5/04/93	5
	90	Snk	SNKTRP	4/21/90	7F7F43071A	EWB90111.SNK	5/19/92	4
	90	Snk	SNKTRP	4/25/90	7F7F443330	EWB90115.SNK	5/27/92	4
	90	Snk	SNKTRP	5/30/90	7F7E516155	EWB90150.SNK	6/18/92	4
	90	Snk	SNKTRP	4/22/90	7F7F443342	EWB90112.SNK	6/04/93	5
	90	Snk	SNKTRP	5/09/90	7F7F365C18	EWB90129.SNK	6/03/93	5
	91	Clw	CLWTRP	5/10/91	7F7D02334A	EWB91130.CLW	5/04 93	4
	91	Clw	CLWTRP	4/05/91	7F7F44011A	EWB91095.CLW	6/01/93	5
	91	Snk	CHANDL	4/24/91	7F7F1F2736	TER01113.2GA	6/17/92	3
	91	Snk	SNKTRP	4/23/91	7F7F534643	EWB91113.PS	5/13/93	4
	91	Snk	SNKTRP	4/30/91	7F7D052F43	EWB91120.PS	5/12/93	4
	91	Snk	SNKTRP	5/26/91	7F7D112671	EWB91146.SNK	6/06/93	4
	91	Snk	SNKTRP	4/29/91	7F7F574C38	EWB91119.SNK	6/25/93	4

‡ R-RT=race-rearing type, MY=migration year, R Site=release site,

10 Appendix D. Detailed listing of adult steelhead returns

Tables 15, 16, and 17 are listings of ail the hatchery, wild, and unknown steelhead returns as of August 4, 1993. Some of the information in PTAGIS2 on the run type was missing in the early years and is assumed to be summer run.

The abbreviations for geographic origin are Clw (Clearwater drainage), Snk (Snake mainstem), Sal (Salmon drainage), and Col (Columbia River). The release site codes can be found in the PSFMC's PIT Tag Specification Document.

The run-rearing type (R-RT) abbreviations are Su, H, W, and U for summer? hatchery, wild, and unknown, respectively.

Table 15: Hatchery steelhead returns to Lower Granite Dam

R-RT‡	MY	Drainage	R Site	R Date	Tag ID	Tag Group	Obs Date
Su-H	87	Snk	Ice Harb	04/23/87	7F7E12344E	LF87.S1A	10/05/89
		Snk	Ice Harb	04/23/87	7F7E202D3C	LF87.S1A	11/02/88
		Snk	Ice Harb	04/23/87	7F7E203A60	LF87.S1A	11/03/88
		Snk	Ice Harb	04/23/87	7F7E22683D	LF87.S1A	09/21/89
		Snk	Ice Harb	04/23/87	7F7E203E74	LF87.S1B	09/26/88
		Snk	Ice Harb	04/27/87	7F7E122B57	LF87.S2A	08/17/88
		Snk	Ice Harb	04/27/87	7F7E207817	LF87.S2A	06/25/89
		Snk	Ice Harb	04/27/87	7F7E121A14	LF87.S2B	10/09/88
		Snk	Ice Harb	05/01/87	7F7E10692A	LF87.S3A	10/09/89
		Snk	Ice Harb	05/01/87	7F7E121C1E	LF87.S3A	09/22/89
		Snk	Ice Harb	05/01/87	7F7E100025	LF87.S3B	09/19/89
		Snk	Ice Harb	05/01/87	7F7E100548	LF87.S3B	09/27/88
		?		04/22/87	7F7E265737	IDFG87.0422	03/23/90
		?	?	05/04/87	7F7E261B12	IDFG87.0504	09/27/89
		?	?	05/08/87	7F7E260A19	IDFG87.0508	10/01/88
	-Es-	Clw	Dwor	03/16/88	7F7E247606	LRB88076.S02	03/19/90
		Clw	Dwor	03/16/88	7F7E24775F	LRB88076.S02	10/09/90
		Clw	Dwor	03/16/88	7F7E237732	LRB88076.S03	09/21/90
		Clw	Dwor	03/16/88	7F7E266039	LRB88076.S04	11/10/90
		Clw	Dwor	03/16/88	7F7E267249	LRB88076.S04	11/04/90
		Clw	Dwor	03/17/88	7F7E24131B	LRB88077.S07	10/16/90
		Clw	Dwor	03/17/88	7F7E33133D	LRB88077.S07	11/08/90
		Clw	Dwor	03/17/88	7F7E233B02	LRB88077.S08	09/29/89
		Clw	Dwor	03/17/88	7F7E236767	LRB88077.S08	11/17/90
		Clw	Dwor	03/17/88	7F7E26280D	LRB88077.S08	11/06/90
		Clw	Dwor	03/17/88	7F7E23606E	LRB88077.S10	11/16/90
		Clw	Dwor	03/17/88	7F7E237C74	LRB88077.S10	10/25/90
		Clw	Dwor	03/17/88	7F7E242B45	LRB88077.S10	04/02/91
		Clw	Dwor	03/17/88	7F7E236659	LRB88077.S 11	04/06/91
		Clw	Dwor	03/17/88	7F7E247C2B	LRB88077.S11	11/05/90
		Clw	Dwor	03/17/88	7F7E322F44	LRB88077.S11	03/24/91
		Clw	Dwor	03/17/88	7F7E323041	LRB88077.S12	11/09/90
		Clw	Dwor	03/17/88	7F7E23780C	LRB88077.S13	10/06/90
		Clw	Dwor	03/17/88	7F7E260D7D	LRB88077.S14	11/22/90
		Clw	Dwor	03/17/88	7F7E263F3D	LRB88077.S14	10/13/90
		Clw	Dwor	03/17/88	7F7E23547F	LRB88077.S15	10/16/90
		Clw	Dwor	03/17/88	7F7E26414E	LRB88077.S15	12/02/90
		Snk	Snktrp	04/21/88	7F7E254735	EWB88112.SNK	10/04/89
		Snk	Snktrp	05/03/88	7F7E263355	EWB88124.SNK	10/04/89
		Clw	Clwtrp	05/02/89	7F7E695F62	EWB89122.CLW	10/31/91
		Snk	HCD	04/25/89	7F7E5E0469	RCD89089.NGA	10/05/90
		Snk	HCD	04/25/89	7F7E647F1F	RCD89089.NGA	09/20/91
		Snk	HCD	04/25/89	7F7E6C3930	RCD89089.NGB	10/01/91
		Snk	HCD	04/25/89	7F7E454A39	RCD89090.NGC	10/02/91
		Snk	HCD	04/25/89	7F7E6C3622	RCD89090.NGC	09/15/90
		Snk	HCD	04/25/89	7F7E45647C	RCD89090.NGD	10/03/91
		Snk	HCD	04/25/89	7F7E514720	RCD89090.NGD	09/17/90
		Clw	Dwor	05/04/89	7F7E650C3D	RCD89082.DW1	10/13/91
		Clw	Dwor	05/04/89	7F7E6C2C66	RCD89082.DW1	03/07/92
		Clw	Dwor	05/04/89	7F7E6C257B	RCD89082.DW2	10/23/91
		Clw	Dwor	05/04/89	7F7E456560	RCD89082.DW3	10/25/91
		Clw	Dwor	05/04/89	7F7E456B7B	RCD89082.DW3	11/14/91
		Clw	Dwor	05/04/89	7F7E457077	RCD89082.DW3	10/06/91
		Clw	Dwor	05/04/89	7F7E457A13	RCD89082.DW3	11/17/91
		Clw	Dwor	05/04/89	7F7E51510E	RCD89082.DW3	09/29/91
		Clw	Dwor	05/04/89	7F7E643E2B	RCD89082.DW3	10/19/90
		Clw	Dwor	05/04/89	7F7E647A03	RCD89082.DW3	10/09/91
		Clw	Dwor	05/04/89	7F7E651B5F	RCD89082.DW3	10/19/90
		Clw	Dwor	05/04/89	7F7E6C360A	RCD89082.DW3	10/29/92
		Clw	Dwor	05/04/89	7F7E456D6F	RCD89083.DW4	10/14/91
		Clw	Dwor	05/04/89	7F7E3F6406	RCD89083.DW5	10/12/91

† Assumedrecov ies with unknown race were summer runs.
‡ R-RT=race-re ng type, MY=migration pear, R Site=release site, R Date=release site.

Su-H	89	Clw	Dwor	05/04/89	7F7E46003C	RCD89083.DW5	04/08/92
		Clw	Dwor	05/04/89	7F7E514D5C	RCD89083.DW5	03/30/93
		Clw	Dwor	05/04/89	7F7E517C2F	RCD89083.DW5	03/31/92
		Clw	Dwor	05/04/89	7F7E652360	RCD89083.DW5	04/05/91
		?	?	03/29/89	7F7E6E4349	RCD89088.MV1	03/31/92
		?	?	03/29/89	7F7E573E7A	RCD89088.MV2	10/22/92
		?	?	03/29/89	7F7E5F685A	RCD89088.MV2	10/14/91
		?	?	03/29/89	7F7E6C4266	RCD89088.MV2	10/14/90
		?	?	03/29/89	7F7E6C5A2D	RCD89088.MV2	09/29/91
		?	?	03/29/89	7F7E6E0379	RCD89088.MV2	10/19/91
		Sal	Sawt	04/13/89	7F7E3F607F	TGC89087.MV2	10/10/91
		Sal	Sawt	04/13/89	7F7E652416	TGC89087.MV2	10/14/90
		Sal	sawt	04/13/89	7F7E5E0638	TGC89087.MV3	09/23/90
		Sal	LSalr	04/22/89	7F7E17427A	LRB89004.MV1	10/31/91
		Sal	LSalr	04/22/89	7F7E203875	LRB89004.MV1	10/07/91
		Sal	LSalr	04/22/89	7F7E415569	LRB89004.MV1	12/14/90
		Sal	LSalr	04/22/89	7F7E415730	LRB89004.MV1	10/04/91
		Sal	LSalr	04/22/89	7F7E415F7A	LRB89004.MV1	10/07/90
		Sal	LSalr	04/22/89	7F7E416106	LRB89004.MV1	11/16/91
		Sal	LSalr	04/22/89	7F7E41625F	LRB89004.MV1	10/01/91
		Sal	LSalr	04/22/89	7F7E604758	LRB89004.MV1	11/13/91
		Sal	LSalr	04/22/89	7F7E604D33	LRB89004.MV1	10/15/91
		Sal	LSalr	04/22/89	7F7E613051	LRB89004.MV1	10/22/91
		Snk	Snktrp	04/19/89	7F7E561831	EWB89109.SNK	10/13/90
		Snk	Snktrp	04/24/89	7F7E3E2E2B	EWB89114.SNK	11/11/90
		Snk	Snktrp	04/27/89	7F7E572A6F	EWB89117.SNK	10/06/91
		Snk	Snktrp	05/08/89	7F7E697269	EWB89128.SNK	10/21/91
	90	Clw	Clwtrp	04/19/90	7F7F36387C	EWB90109.CLW	10/18/92
		Clw	Clwtrp	04/20/90	7F7F372B37	EWB90110.CLW	10/30/92
		Clw	Clwtrp	05/05/90	7F7F360713	EWB90125.CLW	11/02/92
		Clw	Dwor	05/03/90	7F7F3D3C13	LRB90109.DW1	10/22/92
		Clw	Dwor	05/03/90	7F7F3D5561	LRB90109.DW1	04/08/93
		Clw	Dwor	05/03/90	7F7F3F2E28	LRB90109.DW2	03/21/93
		Clw	Dwor	05/03/90	7F7F432876	LRB90109.DW2	10/18/92
		Clw	Dwor	05/03/90	7F7F3C7D54	LRB90110.DW3	10/20/92
		Clw	Dwor	05/03/90	7F7F42635F	LRB90110.DW3	10/04/92
		Clw	Dwor	05/03/90	7F7F430B32	LRB90110.DW3	09/25/92
		Clw	Dwor	05/03/90	7F7F432967	LRB90110.DW3	09/29/92
		Clw	Dwor	05/03/90	7F7F442014	LRB90110.DW3	10/20/92
		Clw	Dwor	05/03/90	7F7F453527	LRB90110.DW3	04/04/93
		Clw	Dwor	05/03/90	7F7F45522D	LRB90110.DW3	10/08/91
		Clw	Dwor	05/03/90	7F7F45583B	LRB90110.DW3	09/28/92
		Clw	Dwor	05/03/90	7F7F455C52	LRB90110.DW3	10/03/92
		Clw	Dwor	05/03/90	7F7F456541	LRB90110.DW3	09/30/92
		Clw	Dwor	05/03/90	7F7F447A75	LRB90110.DW4	10/04/92
		Clw	Dwor	05/03/90	7F7F453A0A	LRB90110.DW4	10/18/92
		Clw	Dwor	05/03/90	7F7F456F4C	LRB90110.DW4	10/03/92
		Clw	Dwor	05/03/90	7F7F447506	LRB90110.DW5	04/08/93
		Clw	Dwor	05/03/90	7F7F455336	LRB90110.DW5	10/06/92
		Clw	Dwor	05/03/90	7F7F456423	LRB90110.DW5	10/13/92
		Clw	Dwor	05/03/90	7F7F433C64	LRB90110.DW6	10/21/92
		Clw	Dwor	05/03/90	7F7F457140	LRB90110.DW6	11/03/92
		Snk	Snktrp	04/17/90	7F7F426E4C	EWB90107.PS	11/15/91
		Snk	Snktrp	04/23/90	7F7F3B590D	EWB90113.SNK	10/13/91
		Snk	Snktrp	04/26/90	7F7F431970	EWB90116.SNK	10/08/91
		Snk	Snktrp	05/01/90	7F7F3F737F	EWB90121.SNK	10/06/91
		Snk	Snktrp	05/02/90	7F7F357C43	EWB90122.SNK	09/29/91
		Snk	Snktrp	05/03/90	7F7F3F5762	EWB90123.SNK	10/06/92
		Snk	Snktrp	05/05/90	7F7F367112	EWB90125.SNK	12/06/91
		Snk	Snktrp	05/08/90	7F7F366132	EWB90128.SNK	09/28/91
		Snk	Snktrp	05/08/90	7F7F36323A	EWB90129.FXW	09/29/91

Su-H	90	Snk	Snktrp	05/08/90	7F7F363E6B	EWB90129.FXW	10/24/92
		Snk	Snktrp	05/09/90	7F7F36693A	EWB90129.SNK	09/22/91
		Snk	Snktrp	05/09/90	7F7F366C5F	EWB90129.SNK	04/10/93
		Snk	Snktrp	05/12/90	7F7F357356	EWB90132.SNK	10/21/92
		Snk	Snktrp	05/12/90	7F7F357507	EWB90132.SNK	10/02/91
		Snk	Snktrp	05/17/90	7F7F3B7123	EWB90137.SNK	10/09/91
		Snk	Snktrp	05/17/90	7F7F3D513E	EWB90137.SNK	09/20/92
		Snk	Snktrp	05/18/90	7F7F3D374E	EWB90138.SNK	09/18/91
		Snk	Snktrp	05/22/90	7F7F435071	EWB90142.SNK	10/09/92
		Snk	Snktrp	05/23/90	7F7E516612	EWB90143.SNK	09/24/92
		Snk	Snktrp	05/25/90	7F7F43480C	EWB90145.SNK	10/08/91
		Snk	Snktrp	05/27/90	7F7F440345	EWB90147.SNK	10/15/91
		Snk	Snktrp	05/28/90	7F7F440A5C	EWB90148.SNK	09/26/92
		Snk	Snktrp	05/28/90	7F7F44466B	EWB90148.SNK	10/30/91
	91	Clw	Dwor	05/01/91	7F7D055244	LRB91053.D5B	10/29/92
		Clw	Dwor	05/01/91	7F7D07223A	LRB91054.18B	04/17/93
		Clw	Dwor	05/01/91	7F7D04205A	LRB91054.51B	10/28/92
		Sal	Sawtrp	04/14/91	7F7D056907	DAC91057.H72	10/09j92
		Sal	Sawtrp	04/14/91	7F7D084A0C	DAC91057.H73	09/27/92
		Sal	Sawtrp	04/14/91	7F7D05781A	DAC91057.H74	09/16/92
		Sal	Sawtrp	04/14/91	7F7D037613	DAC91057.H75	09/26/92
		Sal	Sawtrp	04/14/91	7F7D0F7F70	DAC91057.H75	09/27/92
		Sal	Sawtrp	04/14/91	7F7D06103A	DAC91057.H77	09/27/92
		Sal	Sawtrp	04/14/91	7F7D064801	DAC91057.H78	09/17/92
		Sal	Lsalr	04/24/91	7F7D0F2B62	DAC91058.M7A	10/07/92
		Sal	Lsalr	04/24/91	7F7D0F6E34	DAC91058.M7A	10/07/92
		Sal	Lsalr	04/24/91	7F7D015E09	DAC91058.M8A	10/15/92
		Sal	Lsalr	04/24/91	7F7F0A7114	DAC91058.M8A	11/13/92
		Sal	Lsalr	04/24/91	7F7D0A4C0C	DAC91058.MV7	11/18/92
		Sal	Lsalr	04/24/91	7F7D0E045A	DAC91058.MV7	10/22/92
		Sal	Lsalr	04/24/91	7F7D104813	DAC91058.MV7	09/27/92
		Sal	Lsalr	04/24/91	7F7F063826	DAC91058.MV8	10/06/92
		Sal	Lsalr	04/24/91	7F7F0A604B	DAC91058.MV8	10/03/92
		Sal	Lsalr	04/24/91	7F7F10347A	DAC91058.MV8	04/13/93
		Sal	Lsalr	04/24/91	7F7F761D2A	DAC91058.MV8	11/04/92
		Sal	Lsalr	04/24/91	7F7F7E4375	DAC91058.MV8	10/03/92
		Sal	Salref	04/13/91	7F7D0F2060	DAC91058.MV2	10/03/92
		Sal	Salref	04/13/91	7F7D0F704D	DAC91058.MV2	09/28/92
		Sal	Salrnf	04/20/91	7F7D022E2B	DAC91059.N4B	10/02/92
		Sal	Salrnf	04/20/91	7F7D047A17	DAC91059.N4B	10/02/92
		Sal	Salrnf	04/20/91	7F7D053C0C	DAC91059.N4B	09/17/92
		Sal	Salrnf	04/20/91	7F7D05610D	DAC91059.N4B	09/12/92
		Sal	Salrnf	04/20/91	7F7F7E5F59	DAC91059.N4B	10/09/92
		Sal	Pahsir	04/11/91	7F7D04545F	DAC91059.N7A	10/17/92
		Sal	Pahsir	04/11/91	7F7D055E53	DAC91059.N7A	10/10/92
		Sal	Pahsir	04/11/91	7F7D062061	DAC91059.N7A	10/26/92
		Sal	Pahsir	04/11/91	7F7D046D65	DAC91059.NS7	09/28j92
		Sal	Pahsir	04/11/91	7F7D04766A	DAC91059.NS7	09/24/92
		Sal	Pahsir	04/11/91	7F7D057778	DAC91059.NS7	10/18/92
		Sal	Pahrir	04/11/91	7F7D063003	DAC91059.NS7	09/22/92
		Snk	Snktrp	05/01/91	7F7F531952	EWB91121.SNK	10/26/92
		Snk	Snktrp	05/05/91	7F7D05235A	EWB91125.SNK	11/02/92
		Snk	Snktrp	05/07/91	7F7F4C215E	EWB91127.SNK	10/13/92

Table 16: Wild steelhead returns to Lower Granite Dam

R-RT	MY	Geog	R Site	R Date	Tag ID	Tag Group	Obs Date
Su-W	88	Snk	Snktrp	05/06/88	7F7E26091A	EWB88127.SNK	04/12/90
		Snk	Snktrp	05/06/88	7F7E260C26	EWB88127.SNK	10/11/90
		Snk	Snktrp	05/10/88	7F7E254403	EWB88131.SNK	10/26/90
		Snk	Snktrp	05/13/88	7F7E23621A	EWB88134.SNK	09/20/90
		Sal	PoleC	08/13/87	7F7E200C23	PC87225.1B2	05/02/89
	89	Sal	Salr	08/21/88	7F7E244552	SR234A	05/13/89
		Snk	Snktrp	04/04/89	7F7E3F4809	EWB89094.SNK	10/01/91
		Snk	Snktrp	04/28/89	7F7E516E0C	EWB89118.SNK	02/28/92
		Snk	Snktrp	04/28/89	7F7E517071	EWB89118.SNK	10/05/91
		Snk	Snktrp	04/28/89	7F7E561168	EWB89118.SNK	10/06/91
		Snk	Snktrp	05/01/89	7F7E3F4912	EWB89121.SNK	07/19/91
		Snk	Snktrp	04/28/89	7F7E561A66	EWB89125.SNK	04/01/92
	90	Clw	Clwtrp	05/20/90	7F7F360F13	EWB90140.CLW	09/25/92
		Clw	Clwtrp	05/23/90	7F7F426664	EWB90143.CLW	10/02/91
		Clw	Clwtrp	05/23/90	7F7F427119	EWB90143.CLW	11/24/91
		Snk	Snktrp	04/10/90	7F7E652E40	EWB90100.SNK	09/21/91
		Snk	Snktrp	04/16/90	7F7E652629	EWB90106.SNK	10/02/91
		Snk	Snktrp	04/17/90	7F7E514938	EWB90107.PS	06/10/92
		Snk	Snktrp	04/17/90	7F7E651571	EWB90107.PS	09/23/91
		Snk	Snktrp	04/18/90	7F7F43113A	EWB90108.SNK	09/11/92
		Snk	Snktrp	04/18/90	7F7F43152D	EWB90108.SNK	10/14/91
		Snk	Snktrp	04/19/90	7F7F441520	EWB90109.SNK	09/29/91
		Snk	Snktrp	04/21/90	7F7F425C3E	EWB90111.SNK	09/20/92
		Snk	Snktrp	04/26/90	7F7F44255A	EWB90116.SNK	09/13/92
		Snk	Snktrp	04/26/90	7F7F44310B	EWB90116.SNK	09/18/91
		Snk	Snktrp	04/30/90	7F7F363D71	EWB90120.SNK	09/29/91
		Snk	Snktrp	05/01/90	7F7F482D2A	EWB90121.SNK	10/02/91
		Snk	Snktrp	05/02/90	7F7F3F6368	EWB90122.SNK	04/16/92
		Snk	Snktrp	05/03/90	7F7F3F0D1B	EWB90123.SNK	10/22/91
		Snk	Snktrp	05/06/90	7F7F3F5E38	EWB90126.SNK	03/31/92
		Snk	Snktrp	05/06/90	7F7F402B4D	EWB90126.SNK	09/27/92
		Snk	Snktrp	05/07/90	7F7F35773E	EWB90127.SNK	10/08/91
		Snk	Snktrp	05/07/90	7F7F357F19	EWB90127.SNK	07/18/91
		Snk	Snktrp	05/07/90	7F7F402444	EWB90127.SNK	10/07/92
		Snk	Snktrp	05/07/90	7F7F402D64	EWB90127.SNK	09/24/92
		Snk	Snktrp	05/10/90	7F7F357052	EWB90130.SNK	10/02/91
		Snk	Snktrp	05/11/90	7F7F356F6D	EWB90131.SNK	04/14/93
	91	Clw	Clwtrp	04/12/91	7F7D022E14	EWB91102.CLW	09/20/92
		Clw	Clwtrp	04/26/91	7F7D05243B	EWB91116.FCL	10/09/92
		Clw	Clwtrp	04/26/91	7F7F52575D	EWB91116.FCL	10/15/92
		Snk	Snktrp	04/27/91	7F7F3C252A	EWB91117.SNK	09/25/92
		Snk	Snktrp	04/28/91	7F7F552A1B	EWB91118.SNK	09/17/92
		Snk	Snktrp	05/07/91	7F7F4B4D20	EWB91127.SNK	03/30/93
		Snk	Snktrp	05/10/91	7F7D0D0C07	EWB91130.SNK	10/30/92
		Snk	Snktrp	05/10/91	7F7D0D3B5A	EWB91130.SNK	09/20/92
		Snk	Snktrp	05/10/91	7F7D0E7D0E	EWB91130.SNK	09/25/92
		Snk	Snktrp	05/11/91	7F7F4F3F02	EWB91131.SNK	03/21/93
		Snk	Snktrp	05/12/91	7F7D0C7936	EWB91132.SNK	09/23/92
		Snk	Snktrp	05/12/91	7F7D0F2C13	EWB91133.SN0	10/24/92
		Snk	Snktrp	05/19/91	7F7D0B133E	EWB91139.SNK	09/26/92

R-RT=race-rearing type, MY=migration year, R Site=release site, R Date=release site.