Fish Passage Center Technical Report
2007-1

In-river Survival (LGR to BON, and LGR to MCN) compared to SAR (LGR to LGR) for Snake River yearling chinook and steelhead at 3 Ocean Productivity Levels

By

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Introduction

Recent analyses by NOAA have considered in-river survival (Lower Granite Dam to Bonneville Dam) compared to adult returns and found no relation Mainstem Passage Survival--NOAA presentation to NPCC . A fact sheet on The Federal Caucus website (salmonrecovery.gov) entitled "Facts on 2007 returns of adult spring Chinook to the Columbia and Snake Rivers" quotes NOAA Fisheries as follows; "According to NOAA Fisheries Science Center, the percentage of juvenile spring Chinook salmon that survive the migration through the dams on the Snake and Columbia Rivers on their way to the ocean has little correlation to their subsequent adult return rate." From their finding a lack of a relationship, NOAA has suggested it would be difficult to determine reach survival standards relevant to recovery of endangered stocks. One might infer that because no significant relation between juvenile survival and adult return has been found that no improvement in hydrosystem survival is necessary to recover endangered stocks. Logically, it follows that improving in-river survival and in-river conditions for passage of juvenile fish, should lead to improvements in adult returns. Based on recent attempts by NOAA the connection between juvenile hydrosystem survival and adult returns has remained obscured.

However the analytical approach used by NOAA did not account for the role of ocean productivity on adult returns. Studies documenting the influence of ocean climate regimes on adult salmon survival have left little doubt that ocean productivity has a large impact on salmon production. Several papers addressing this issue as it pertains to Columbia River salmon and other geographically linked populations of salmon have expanded upon the basic links between climate indices and salmon returns put forward by Mantua et al 1997. Specifically, Schaller and Petrosky 2007, Schaller et al 2007, Scheuerell and Williams 2005, have demonstrated links between ocean indices and various measures of adult ocean survival, such as SAR (smolt to adult return rate), S/R (spawner recruit) and S3 (first year ocean survival). Scheuerell and Williams 2005 argued convincingly about the importance of ocean conditions for survival of salmon to adult return. They identified several indices such as PDO (Pacific Decadal Oscillation) and upwelling and discussed potential reasons those indices might improve ocean survival for salmon. Schaller and Petrosky 2007 also linked water transit time, an environmental condition that affects juvenile salmon, with ocean indices and adult returns. Their paper laid the theoretical ground work for this analysis. Our findings, suggest that when you use ocean productivity to account for that part of survival attributable to the ocean, there is a strong relationship between in-river survival and adult return for Snake River spring\summer Chinook and steelhead.

Methods

Juvenile Reach Survival

Survival estimates were produced for yearling chinook and steelhead that migrated during the years 1995 to 2005 in the reach Lower Granite Dam to McNary Dam and for the years 1998 to 2005 in the reach Lower Granite Dam to Bonneville Dam. Passage date at Lower Granite Dam and travel time to Little Goose Dam was used to group juvenile migrants into 5 discrete two-week cohorts for each year.

Unlike prior analyses of juvenile reach survival that include fish detected or released at Lower Granite Dam, a new approach (at least for juvenile salmon reach survival estimates) was developed that included fish first detected at Little Goose Dam as part of the survival cohort. The benefit of this new approach was to increase PIT-tag cohort sizes so that more time periods were included during each year. Additionally, greater tag numbers result in lower variances for reach survival estimates.

Fish travel time from Lower Granite Dam to Little Goose Dam was calculated for fish detected at Lower Granite that passed during a two-week date range and were subsequently detected at Little Goose Dam. Based on median travel time for the cohort, fish first detected at Little Goose Dam during the two week period adjusted by travel time were then added to the release at Lower Granite Dam. For example, if fish detected at Lower Granite Dam during April 8 to April 21 time period had a median travel time of 3 days to Little Goose Dam, then those fish arriving at Little Goose Dam from April 11 to April 24, that had not been detected at Lower Granite Dam, were added to the re-release group at Little Goose Dam. These fish were assumed, based on similar arrival timing, to have passed Lower Granite Dam at the same time as detected fish, but through other routes, that did not have PIT-tag detection capability, such as turbines and spill. For each two-week interval of passage at Lower Granite Dam, survival was estimated using Cormack-Jolly-Seber methodology.

The key underlying assumptions of the new approach were consistent with the Cormack-Jolly- Seber survival method assumptions (Burnham et al., 1987). The new method assumed detected and undetected fish at Lower Granite Dam were equally mixed, survived at an equal rate over the reach, and had equal detection probability at Little Goose Dam, as well as subsequent dams downstream. The new cohort included fish released or detected at Lower Granite Dam, and additional fish that, based on travel time, passed Lower Granite Dam undetected during the same time period, and then arrived at Little Goose Dam mixed with the initial release group. The approach has been used in other types of CJS single-age mark-recapture survival estimation (see Williams et al 2002), but to our knowledge it is the first such application of this method to juvenile salmon reach survival analyses on the Columbia River. For that reason we expand upon the approach in the methods and results sections as well.

The standard closed form survival estimate for the first reach from Lower Granite Dam to Little Goose Dam was calculated as follows:

$$S_1 = \frac{m_2 + z_2\left(\frac{R_2}{r_2}\right)}{R_1} \qquad (1)$$

Where,

S_1 = Survival LGR to LGS
R_1 = fish released or detected at LGR
m_2 = fish detected at LGS
z_2 = detects of fish not detected at LGS

R_2 = fish released at LGS, either having been detected at LGR or first time detects at LGS
r_2 = subsequent detections of fish released at LGS

The R_2 release in equation 1 was made up of fish released at Lower Granite Dam, detected and re-released (bypassed) at Little Goose Dam designated R_{2x11}, and first time detected fish re-released at Little Goose Dam R_{2x01}. Since the S_1 estimate is a ratio of two population estimates, the effect of adding fish at Little Goose Dam R_{2x01} would primarily affect the ratio R_2/ r_2. This ratio multiplied by z_2, the downstream detections of fish unseen at Little Goose, is the estimate of the undetected population at Little Goose Dam. Concern about potential bias would be warranted, if previously undetected (R_{2x01}) and previously detected fish (R_{2x11}) had different detection probabilities downstream of Little Goose Dam. However, we did not anticipate that this would be the case, and if it were, it would violate the assumptions of the CJS model, such that the reach estimate would be biased.

To assess potential unanticipated bias associated with the new method, we compared the new estimates of reach survival that contained Lower Granite and Little Goose releases with the more traditional approach (using only Lower Granite detections). The effect on reach survival estimates of adding in fish detected at Little Goose Dam was evaluated using a dataset of subyearling Chinook survival estimates in the reach Lower Granite Dam to McNary Dam as well as steelhead reach survival estimates from Lower Granite Dam to Bonneville Dam from the dataset generated for this analysis. The original estimates with only Lower Granite detects were plotted against the modified estimates for the same Lower Granite Passage period using both Little Goose and Lower Granite detected fish.

Smolt to Adult Survival or Returns (SAR)

The overall population of juvenile migrants destined to migrate in-river was expressed in Lower Granite Dam equivalents by tracking fish removed for transportation or added at Little Goose Dam as described above, and expressing those removals or additions in equivalents at LGR based on survival to the downstream dam. Other removals at Lower Monumental or McNary dams (the other two transport sites) were also expressed in Lower Granite equivalents and removed from the starting population. This approach to estimating the Lower Granite starting population was developed for the Comparative Survival Study and theoretical considerations as well as detailed statistical derivations are well defined in (Schaller et al 2007).

For each two week juvenile cohort, the starting population, or estimated Lower Granite Equivalent population destined to migrate in river was calculated;

$$\mathrm{LGRE}_{\mathrm{Pop}} = \mathrm{R}_1 + \frac{\mathrm{R}_{2x01}}{\mathrm{S}_1} - \frac{\mathrm{t}_2}{\mathrm{S}_1} - \frac{\mathrm{t}_3}{\mathrm{S}_1 \bullet \mathrm{S}_2} - \frac{\mathrm{t}_4}{\mathrm{S}_1 \bullet \mathrm{S}_2 \bullet \mathrm{S}_3} \quad (2)$$

Where,

S_1 = Survival Lower Granite Dam to Little Goose Dam
S_2 = Survival Little Goose to Lower Monumental Dam
S3 = Survival Lower Monumental Dam to McNary Dam
t_2 = fish transported or removed at Little Goose Dam
t_3 = fish transported or removed at Lower Monumental Dam
t_4 = fish transported or removed at McNary Dam

In effect, fish removed for transportation or other purposes, reduced the starting population at Lower Granite Dam that would be used to calculate the in-river SAR back to that site. The additional fish first detected and re-released at Little Goose Dam (R_{2x01}) increased the starting population.

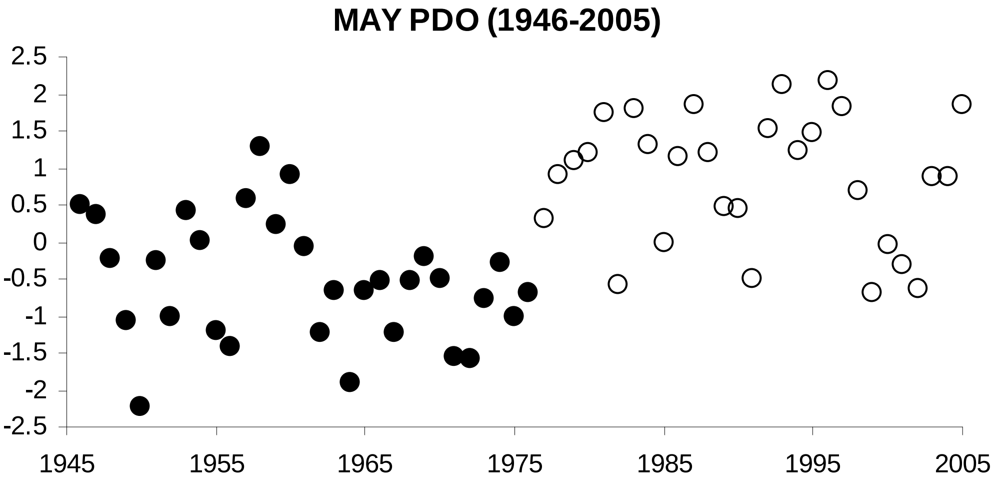
Once the population at Lower Granite Dam destined to migrate in river was estimated, PIT-tag adult returns to Lower Granite Dam were counted. Returns were sorted based upon ocean age (e.g. minijacks would be 0-ocean, jacks were 1-ocean, 2-ocean, 3-ocean). The smolt to adult return rates from Lower Granite starting juvenile population to adult returns, $SAR_{lgrtolgr}$ were calculated based on the number of adult returns AR_{lgr} divided by the in-river population (see equation 3 below). For yearling chinook, minijacks and jacks (0-ocean and 1-ocean) were not included in the adult return numbers, while for steelhead 1-ocean and older returns were considered adults.

$$SAR_{lgrtolgr} = \frac{AR_{lgr}}{LGRE_{pop}} \quad (3)$$

Ocean Indices

Ocean indices were used to characterize the ocean productivity that juvenile fish would experience the year of ocean entry. So for juvenile salmon that migrated in-river in1995, indices would be assigned from that calendar year. Several indices were used in the analysis based on their correlations to SAR's, S/R, and first year ocean survival (S3) as shown by Scheuerell and Williams 2005, Schaller and Petrosky 2007: April and October Upwelling at transect Latitude 122 W, Longitude 45 N were used. Units are cubic meters/second/100 meters of coastline. Data were obtained from NOAA Pacific Fisheries Environmental Laboratory at the following link: www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/upwelling.html. May and September Pacific Decadal Oscillation (PDO) for the North Pacific were also used. The Pacific Decadal Oscillation (PDO) Index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N for the 1900-93 periods). Data were obtained from The Joint Institute for the Study of the Atmosphere and Ocean at http://jisao.washington.edu/pdo/.

A significant regime shift occurred in the mid-1970's with a larger proportion of warm PDO values occurring after 1976 (Hare and Mantua 2000). Since our survival data was all within the latter time period we included years 1977 to 2006 for our classification procedure. Ocean productivity classification was assigned for each year based on the four indices listed above. The time series provided 18 years of information prior to 1995 - the first year of the survival analysis.



1977 regime shift identified in Hare and Mantua (2000)

Figure 1. May PDO, one of four ocean indices used in our analysis, demonstrates the regime shift identified by Hare and Mantua that occurred around 1976-1977.

For each of the ocean indices, the best one third of the years were assigned to ocean productivity category “good”, the middle one third of years to “moderate” and the worst one third of years to “poor” . After all years were assigned to these categories, criteria for relatively good, moderate and poor ocean conditions were combined. Each year was then assigned to good, moderate or poor ocean productivity category based on the number of indices which fell into each of those categories (see Table 1).

Table 1. Possible combinations of ocean index ranks and the resulting overall category assigned to each year based those ranks.

Ranks assigned to four indices each year			Overall Category
Good (3)	**Moderate (2)**	**Poor (1)**	
3	1	0	good
3	0	1	good
2	2	0	good
2	1	1	good
1	2	1	moderate
1	3	0	moderate
0	3	1	moderate
2	0	2	moderate
1	0	3	poor
0	1	3	poor
0	2	2	poor
1	1	2	poor

So, for example, if a year had 3 of 4 ocean indices in the good category, and 1 of 4 the moderate category, that year would receive an overall good rank, while if 3 indices were poor and 1 were good that year would receive a poor rank. And, if two indices were good and two bad, the overall rank would be moderate. The ranking procedure separated years based on the relative score of the indices assigned. Therefore the productivity rankings that resulted were relative to other recent years and for that reason may not be useful to understand historical ocean productivity prior to the regime shift.

Results

Juvenile Reach Survivals and SAR's

Juvenile survival data is summarized in Tables 2 through 5. Survivals ranged from 3% in 2001 to nearly 70% in 1998 for steelhead in the Lower Granite to Bonneville Dam reach (Table 2), while survivals in the same reach for yearling spring/summer Chinook ranged from 25% in 2001 to 83% in 1998 (Table 4).

Insufficient tags were available in all time periods to estimate survival from Lower Granite to Bonneville or from Lower Granite to McNary Dam. However, during most years at least two estimates of survival were possible while in others up to 5 estimates were available, particularly for the shorter Lower Granite to McNary Dam reach (Tables 3 and 5). SAR's ranged between 0 and 0.037 for steelhead, while the yearling Chinook SAR's varied between 0 and 0.023.

Table 2. Juvenile Steelhead Survival from Lower Granite Dam to Bonneville Dam and corresponding adult return rate to Lower Granite Dam.

Migration Year	Date Range	LGR to BON juvenile Survival	LGR to LGR Smolt to Adult Return Rate
1998	4/22 to 5/5	0.692	0.003
1998	5/20 to 6/02	0.124	0.003
1999	4/8 to 4/21	0.439	0.008
1999	4/22 to 5/5	0.549	0.037
1999	5/6 to 5/19	0.478	0.006
1999	5/20 to 6/02	0.408	0.005
2000	4/8 to 4/21	0.616	0.027
2000	4/22 to 5/5	0.564	0.018
2000	5/6 to 5/19	0.275	0.006
2001	4/22 to 5/5	0.037	0.000
2001	5/6 to 5/19	0.030	0.000
2002	4/8 to 4/21	0.629	0.016
2002	4/22 to 5/5	0.356	0.006
2002	5/6 to 5/19	0.235	0.006
2002	5/20 to 6/02	0.318	0.005
2002	6/03 to 6/16	0.091	0.001
2003	4/8 to 4/21	0.526	0.015
2003	4/22 to 5/5	0.400	0.007
2003	5/6 to 5/19	0.443	0.004
2003	5/20 to 6/02	0.438	0.002
2004	5/6 to 5/19	0.117	0.001
2005	4/22 to 5/5	0.284	0.001
2005	5/6 to 5/19	0.377	0.001

Table 3. Juvenile Steelhead Survival from Lower Granite Dam to McNary Dam and corresponding adult return rate to Lower Granite Dam.

Migration Year	Date Range	LGR to McN juvenile Survival	LGR to LGR Smolt to Adult Return Rate
1996	4/22 to 5/5	0.760	0.004
1996	5/6 to 5/19	0.758	0.000
1997	4/8 to 4/21	0.780	0.001
1997	4/22 to 5/5	0.839	0.004
1997	5/6 to 5/19	0.973	0.002
1998	4/8 to 4/21	0.571	0.007
1998	4/22 to 5/5	0.682	0.003
1998	5/6 to 5/19	0.658	0.002
1998	5/20 to 6/2	0.615	0.003
1999	4/8 to 4/21	0.712	0.008
1999	4/22 to 5/5	0.675	0.037
1999	5/6 to 5/19	0.646	0.006
1999	5/20 to 6/2	0.733	0.005
1999	6/3 to 6/16	0.404	0.001
2000	4/8 to 4/21	0.735	0.027
2000	4/22 to 5/5	0.620	0.018
2000	5/6 to 5/19	0.500	0.006
2000	5/20 to 6/2	0.510	0.002
2001	4/8 to 4/21	0.242	0.000
2001	4/22 to 5/5	0.173	0.000
2001	5/6 to 5/19	0.154	0.000
2001	5/20 to 6/2	0.071	0.000
2001	6/3 to 6/16	0.037	0.000
2002	4/8 to 4/21	0.764	0.016
2002	4/22 to 5/5	0.500	0.006
2002	5/6 to 5/19	0.454	0.006
2002	5/20 to 6/2	0.556	0.005
2002	6/3 to 6/16	0.272	0.001
2003	4/8 to 4/21	0.664	0.015
2003	4/22 to 5/5	0.595	0.007
2003	5/6 to 5/19	0.563	0.004
2003	5/20 to 6/2	0.602	0.002
2003	6/3 to 6/16	0.373	0.000
2004	4/8 to 4/21	0.577	0.004
2004	4/22 to 5/5	0.515	0.003
2004	5/6 to 5/19	0.308	0.001
2004	5/20 to 6/2	0.334	0.000
2004	6/3 to 6/16	0.187	0.001
2005	4/8 to 4/21	0.482	0.006
2005	4/22 to 5/5	0.604	0.001
2005	5/6 to 5/19	0.632	0.001
2005	5/20 to 6/2	0.312	0.000
2005	6/3 to 6/16	0.197	0.000

Table 4. Juvenile Spring/Summer Chinook Survival from Lower Granite Dam to Bonneville Dam and corresponding adult return rate to Lower Granite Dam.

Migration Year	Date Range	LGR to BON juvenile Survival	LGR to LGR Smolt to Adult Return Rate
1998	4/8 to 4/21	0.478	0.010
1998	4/22 to 5/5	0.827	0.005
1998	5/6 to 5/19	0.481	0.004
1999	4/8 to 4/21	0.559	0.010
1999	4/22 to 5/5	0.541	0.014
1999	5/6 to 5/19	0.574	0.014
1999	5/20 to 6/2	0.636	0.018
2000	4/8 to 4/21	0.726	0.023
2000	4/22 to 5/5	0.524	0.017
2000	5/6 to 5/19	0.505	0.015
2001	4/8 to 4/21	0.294	0.001
2001	4/22 to 5/5	0.284	0.001
2001	5/6 to 5/19	0.253	0.000
2002	4/8 to 4/21	0.627	0.006
2002	4/22 to 5/5	0.680	0.006
2002	5/6 to 5/19	0.651	0.007
2002	5/20 to 6/2	0.729	0.011
2003	4/8 to 4/21	0.565	0.002
2003	4/22 to 5/5	0.577	0.002
2003	5/6 to 5/19	0.570	0.003
2003	5/20 to 6/2	0.530	0.001
2004	4/8 to 4/21	0.376	0.002
2004	4/22 to 5/5	0.401	0.001
2004	5/6 to 5/19	0.360	0.001
2004	5/20 to 6/2	0.573	0.002
2005	4/8 to 4/21	0.569	0.001
2005	4/22 to 5/5	0.450	0.001
2005	5/6 to 5/19	0.600	0.001
2005	5/20 to 6/2	0.309	0.000

Table 5. Juvenile Spring/Summer Chinook Survival from Lower Granite Dam to McNary Dam and corresponding adult return rate to Lower Granite Dam.

Migration Year	Date Range	LGR to McN juvenile Survival	LGR to LGR Smolt to Adult Return Rate
1995	4/8 to 4/21	0.884	0.003
1995	4/22 to 5/5	0.724	0.003
1995	5/6 to 5/19	0.729	0.001
1995	5/20 to 6/2	0.456	0.004
1996	4/8 to 4/21	0.789	0.002
1996	4/22 to 5/5	0.710	0.001
1996	5/6 to 5/19	0.729	0.002
1997	4/8 to 4/21	0.733	0.006
1997	4/22 to 5/5	0.695	0.007
1997	5/6 to 5/19	0.733	0.005
1997	5/20 to 6/2	0.732	0.001
1998	4/8 to 4/21	0.702	0.010
1998	4/22 to 5/5	0.788	0.005
1998	5/6 to 5/19	0.794	0.004
1999	4/8 to 4/21	0.728	0.010
1999	4/22 to 5/5	0.787	0.014
1999	5/6 to 5/19	0.796	0.014
1999	5/20 to 6/2	0.803	0.018
2000	4/8 to 4/21	0.875	0.023
2000	4/22 to 5/5	0.729	0.017
2000	5/6 to 5/19	0.729	0.015
2001	4/8 to 4/21	0.611	0.001
2001	4/22 to 5/5	0.586	0.001
2001	5/6 to 5/19	0.489	0.000
2002	4/8 to 4/21	0.661	0.006
2002	4/22 to 5/5	0.718	0.006
2002	5/6 to 5/19	0.678	0.007
2002	5/20 to 6/2	0.755	0.011
2003	4/8 to 4/21	0.729	0.002
2003	4/22 to 5/5	0.736	0.002
2003	5/6 to 5/19	0.721	0.003
2003	5/20 to 6/2	0.826	0.001
2004	4/8 to 4/21	0.719	0.002
2004	4/22 to 5/5	0.686	0.001
2004	5/6 to 5/19	0.676	0.001
2004	5/20 to 6/2	0.818	0.002
2005	4/8 to 4/21	0.671	0.001
2005	4/22 to 5/5	0.754	0.001
2005	5/6 to 5/19	0.757	0.001
2005	5/20 to 6/2	0.626	0.000

Ocean Indices

The overall productivity category assigned to each year are shown in Table 6. The ocean productivity ranking system we used produced a good contrast of indices for the years when reach survival and SAR's were calculated; 1995 to 2005. The pattern in ocean productivity we assigned to the years 1995 to 2005 matched fairly well with the pattern of years described by Scheuerell and Williams 2005. April upwelling is generally positively correlated with good ocean productivity, while May PDO, September PDO, and October Upwelling are negatively correlated with good ocean productivity. Sheuerell and Williams 2000 provides some discussion of potential ecological significance of these indices.

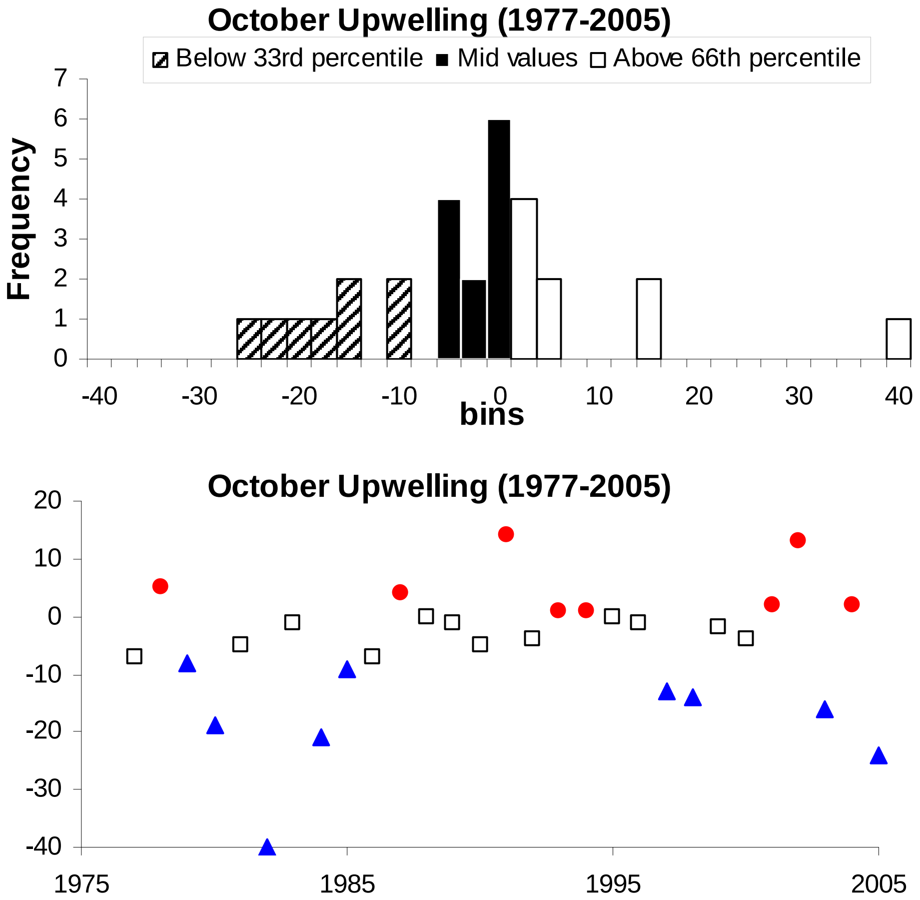


Figure 2. Results of ranking procedure used to divide years based on assigning approximately 1/3 years into each of 3 categories (upper panel) and resulting overall ranks for years (lower figure) showing the October upwelling values and what overall ocean category was assigned to each year. In the case of October upwelling, the index corresponded quite well with the overall productivity ranking indicated by the colored symbols in the lower panel (red circle - poor ocean productivity year, clear square - moderate, blue triangle good ocean productivity).

Table 6. Ocean indices of productivity and relative productivity category assigned based on relative ranking system of assigning best 1/3 as 'good', worst 1/3 as 'poor' and middle 1/3 as 'moderate' to ocean indices based on the years 1977 to 2006. The relative productivity category shown below is the result of combining the ranks for the 4 ocean indices.

Year	Ocean Indices of Productivity and Scores				Ocean Productivity Category
	April Upwelling	May PDO	September PDO	October Upwelling	
1995	2	1.46	1.16	0	poor
1996	-53	2.18	0.24	-1	poor
1997	-2	1.83	2.19	-13	poor
1998	9	0.7	-1.21	-14	good
1999	31	-0.68	-1.53	-2	good
2000	0	-0.05	-1.24	-4	good
2001	0	-0.3	-1.37	2	good
2002	17	-0.63	0.43	13	good
2003	-17	0.89	0.01	-16	moderate
2004	1	0.88	0.75	2	poor
2005	-10	1.86	-0.46	-24	moderate

Relationship between Juvenile Survival in two reaches and SAR LGR to LGR

The results showed that when ocean productivity was taken into account, there was a strong relationship between in-river survival and adult return rates for both Snake River spring/summer Chinook and Snake River steelhead (Figures 3 and 4). Seven of the eight curves fitted resulted in p values below 0.10, with 6 having p values below 0.01. Multiple R^2 values ranged from 0.38 to 0.82. By separating survival groups into poor, moderate and good ocean groups, the effect of ocean productivity was held relatively constant for each category, so that the effects of in-river survival on adult return rates could be more easily evaluated. Logistic regression lines were fitted to the data for good and moderate ocean productivity categories. For the curve fitting, a value of 0.00001 was added to 0 values so that a logistic function could be used. It is likely the curves would plateau at some SAR value well above the range of values observed in recent years; in which case the relationship might look more like a classic S-shaped logistic curve.

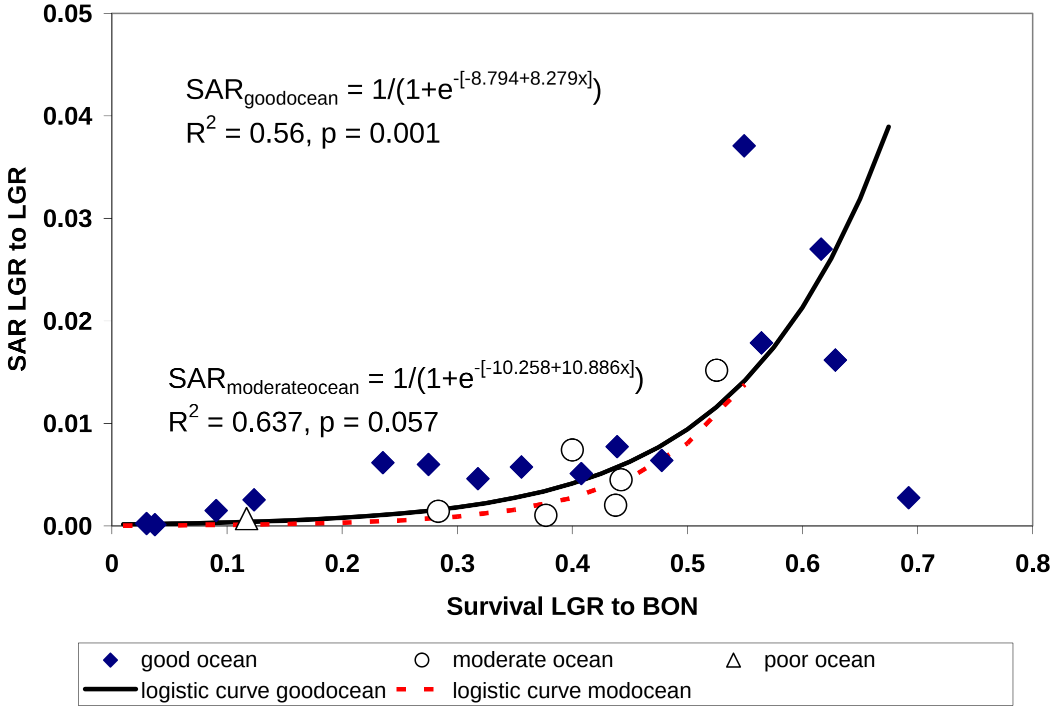


Figure 3a. Steelhead reach survival LGR to BON plotted against SAR LGR to LGR for the years 1998 to 2005 under good, moderate and poor ocean productivity categories.

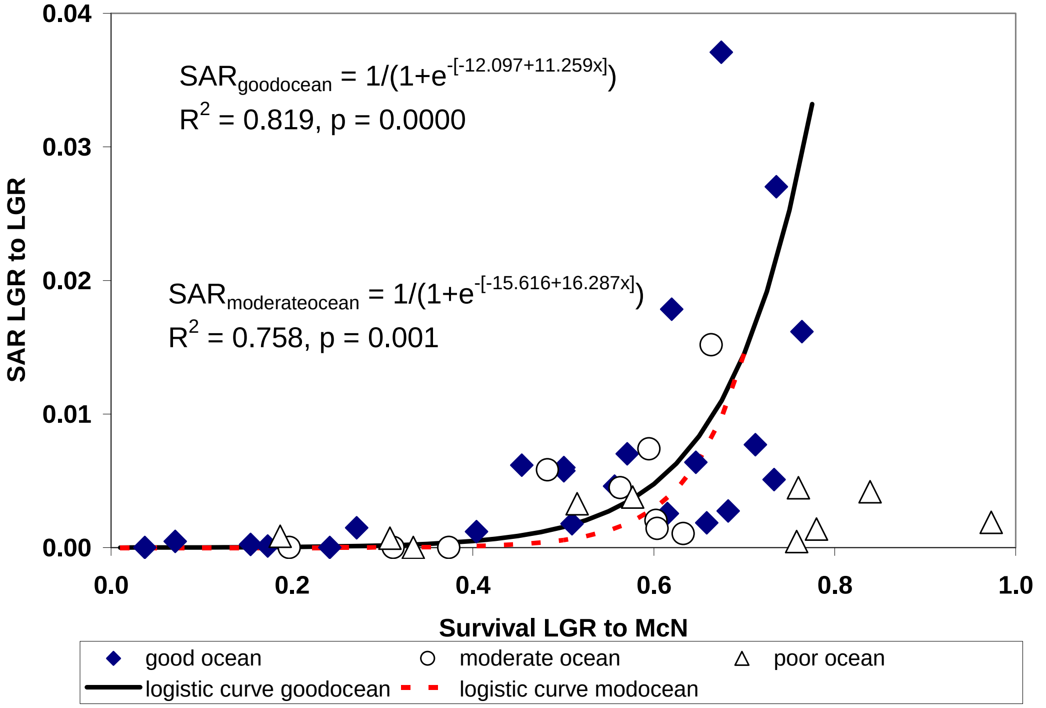


Figure 3b. Steelhead reach survival LGR to McN plotted against SAR LGR to LGR for the years 1995 to 2005 under good, moderate and poor ocean productivity categories.

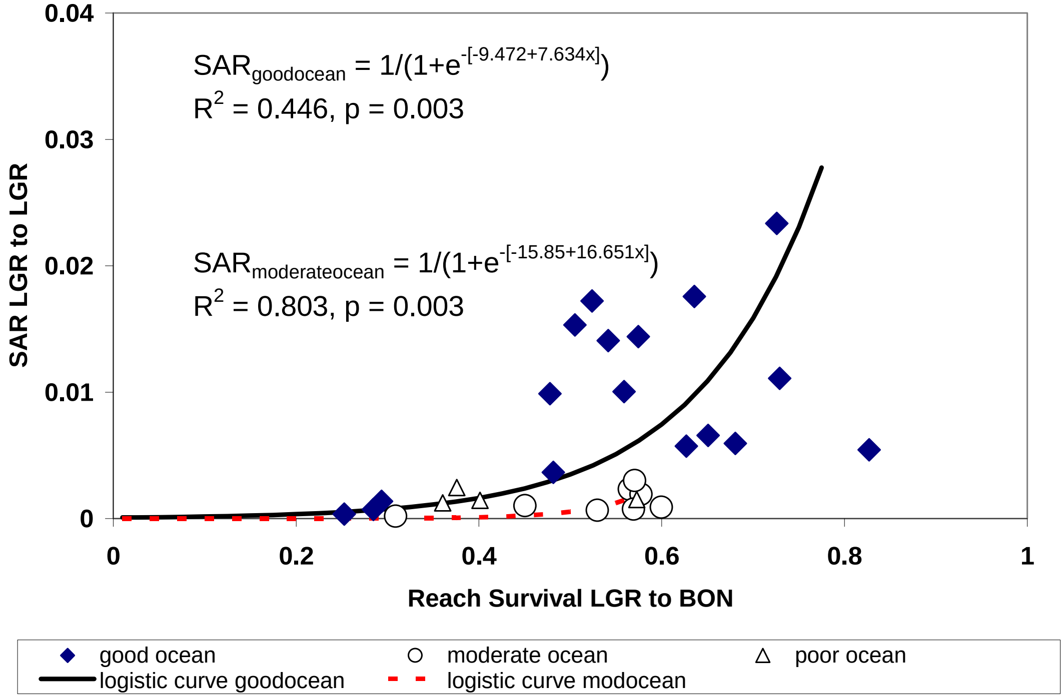


Figure 4a. Yearling spring\summer Chinook reach survival LGR to BON plotted against SAR LGR to LGR for the years 1998 to 2005 under good, moderate and poor ocean productivity categories.

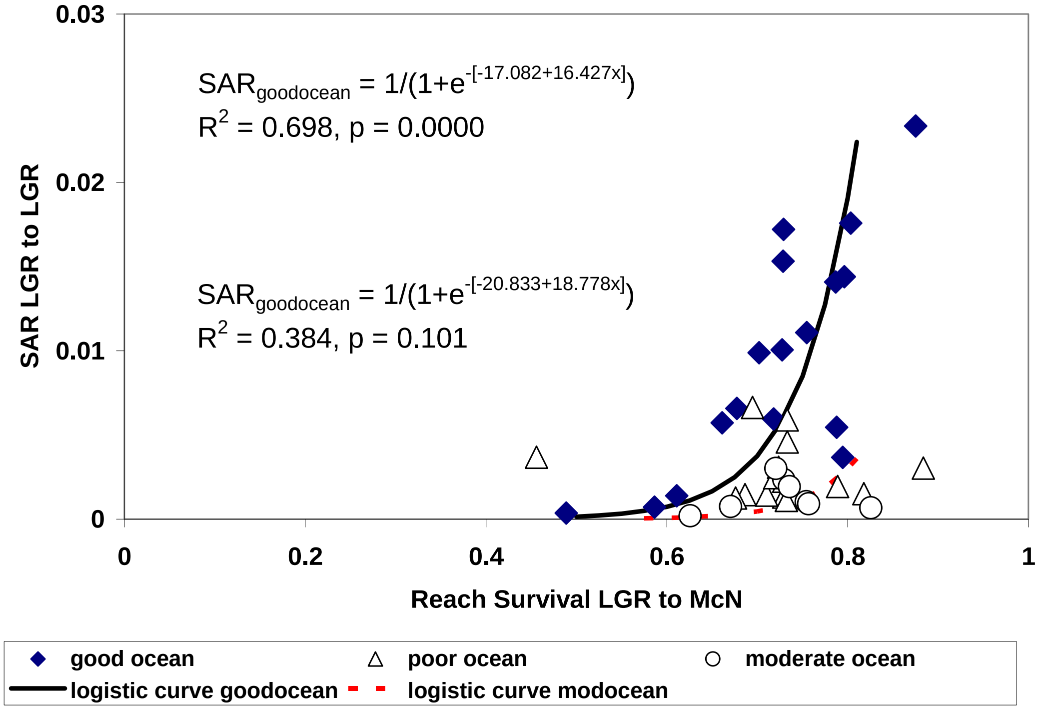


Figure 4b. Yearling spring\summer Chinook reach survival LGR to McN plotted against SAR LGR to LGR for the years 1995 to 2005 under good, moderate and poor ocean productivity categories.

Exploration of potential bias in modified reach survival estimates

Our analysis of possible bias in reach survival estimates in which fish were added at Little Goose Dam suggested no biologically significant bias in modified reach estimates. The modified estimates differed from the original estimates. But it was anticipated that adding additional tags to the starting population, would cause the modified cohort estimates to vary somewhat from the original estimates. What was of concern was potential systematic bias through all the reach estimates. In Figure 5 a small bias effect was exhibited in the Steelhead survival dataset used in this analysis. At high reach survivals the new method resulted in slight negative bias in reach survival. While the bias was identified and found significant using a Wilcoxon signed-rank test (Mendenhall et al 1981), the biological significance of this bias is minimal compared to the original method that used only fish detected or released at Lower Granite Dam. And the impact of such a bias in the overall reach survival estimate as part of this analysis was considered negligible. In fact, it was impossible to decide which approach yielded a reach survival estimate more representative of the untagged population. Since the new method estimates were always well within 95% confidence bounds of the original method, the bias exploration led to interesting questions, but further exploration of the cause of that bias was considered unimportant for and beyond the scope of this analysis.

We concluded that the new approach of adding tags to the releases at Little Goose Dam was appropriate and so it was adopted for all analyses in this paper. The modified method increased the number of PIT-tags available, especially for yearling chinook estimates, which allowed for up 5 two-week LGR to BON reach survival cohorts during each year for this analysis. The additional tags also improved precision of the reach estimates.

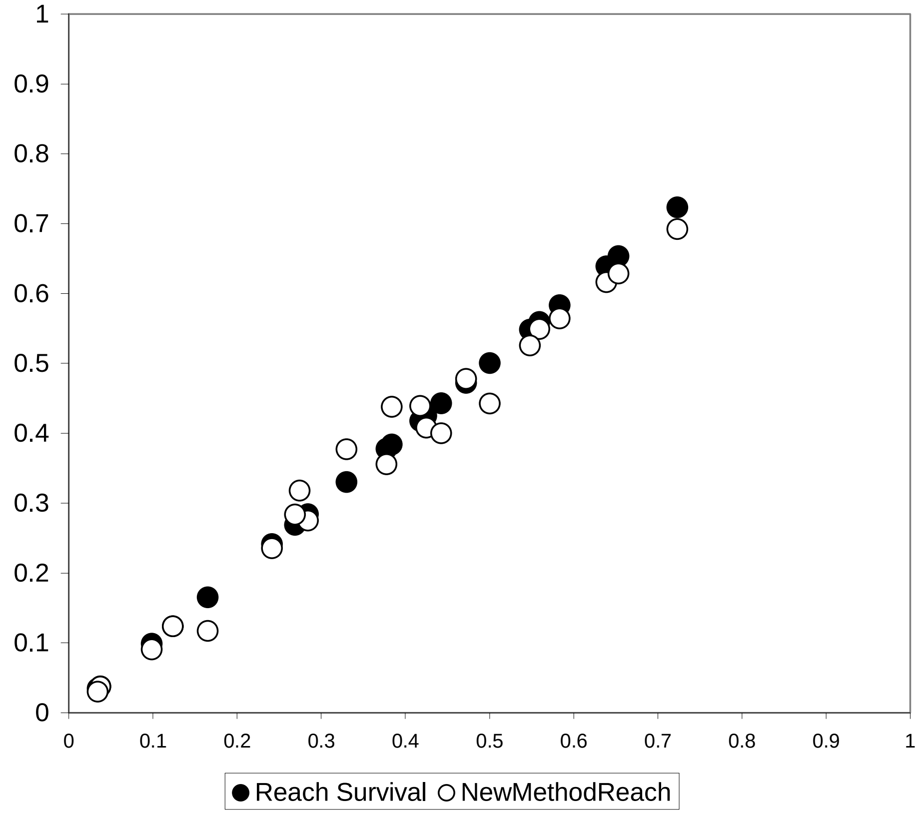


Figure 5. Steelhead survival estimates in the reach Lower Granite Dam to Bonneville Dam. Original estimates using fish detected at LGR were plotted against themselves (1:1 line dark circles). Then the modified estimates (open circles) were plotted against the original estimates to explore potential systematic bias in the modified approach.

Discussion

The use of regression analysis to describe the relationship between juvenile survival and adult return rates can be difficult because the assumption of independence is likely violated when adult return rates are in part a function of juvenile reach survival, which was here treated as an independent variable. However, this analysis was an exploration of the nature of the relationship between juvenile survival and adult returns by which the existence of the inter-relationship, which had been called into question, was reconfirmed. For that reason the use of regression analysis is justified. Further analysis of juvenile salmon hydrosystem passage can use this approach as a foundation for analyzing physical variables fish experienced in the hydrosystem.

Our analysis shows that in-river survival has significant correlation to adult returns when ocean productivity changes are accounted. In years when in-river survivals were high and ocean productivity was high, or even moderate according to our ranking system, the SAR's were high. Conversely, when reach survivals were low, even in years when ocean indices suggested good or moderate ocean productivity SAR's were poor. And, when either in-river survival was low, or ocean productivity was in the poor category, SAR's were low. These basic relationships support that to achieve good adult returns rates good in-river survival rates are needed regardless of ocean conditions.

Typically reach survival from Lower Granite Dam to Bonneville Dam ranges between 30 and 70 percent for yearling Chinook and Steelhead, - averaging less than 50% for steelhead, and just over 50% for Chinook. Our analysis is compelling evidence for seeking reach survivals above what we are currently achieving. In fact, the shape of the relationship, the exponential curves fitted to our data sets, suggests that any improvement in reach survival beyond the average of roughly 50 percent could produce relatively large improvements in adult return rates, when ocean productivity is moderate to good.

As we begin to better understand the influence of the ocean productivity on adult returns, it will allow further refinement of this sort of analysis, taking account of environmental factors as fish migrate through the hydrosystem, and directly assessing their impacts on adult returns. The strength in this approach is that the influence of factors affecting both in-river survival and delayed hydrosystem mortality, such as spill passage proportion and fish travel time, and arrival timing at the estuary, could be assessed simultaneously. The results might better inform future management actions, so that standards achieve more than just project-by-project or reach-by-reach goals, but instead achieve improved adult returns.

The recent ocean regime shift that occurred in 1976-77 may have favored Alaskan fisheries over Columbia River stocks as suggested by Mantua et al.1997. However, within this current regime (that may be less than ideal for endangered stocks affected by the Federal Columbia River Power System (FCRPS)) it appears that recovery level returns of 3 to 6% are possible for in-river migrants with improvements in juvenile survival under most ocean conditions.

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