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MEMORANDUM

TO: Scott Marshall, USFWS

FROM: Michele DeHart

DATE: January 18, 2007

RE: Associations between upstream migration success and smolt outmigration history for returning adult Snake River-origin hatchery and wild summer steelhead

In response to your 5 December 2006 request, the FPC staff analyzed associations between juvenile transportation and adult homing success for Snake River summer steelhead of hatchery and wild origin. We approached this task in a manner similar to prior analyses investigating linkages between spring/summer Chinook salmon conversion rates and juvenile transportation history (e.g., Berggren et al. 2006). Thus, using the available PIT-tag data, we compared measures relating to the homing behavior and upstream migration success of returning adult steelhead between groups of individuals that out-migrated via inriver and juvenile-transportation (i.e., barge and truck) passage routes. Also, we assessed the level of straying exhibited by returning adult steelhead in these two groups. Our analysis should be viewed as complementary to the recent University of Idaho technical publication (Keefer et al. 2006), as it draws (in part) on a common PIT-tagging effort (i.e., NOAA-Fisheries' transportation studies)[1]. Our findings can be summarized as follows:

- Returning adults that were transported as juveniles were significantly less successful ($\sim$10% reduction) at homing to their natal basin (i.e., above LGR) than those with

[1] Our analysis draws on records of fish marked both at and above Lower Granite Dam, due to the limited number of PIT-tagged returning-adult steelhead available. The Keefer et al. (2006) study was limited to a subset of the Lower Granite marks listed in our Table 1. Our work additionally includes return years 2004 and 2005 and incorporates detections at all BON adult ladders (i.e., see J. Williams's comment in the 5 January 2007 Columbia Basin Bulletin).

inriver out-migration histories. This differential includes losses due to straying, harvest, and other agents of mortality.

- Transported adult steelhead returned to BON slightly later (particularly hatchery steelhead) and took a significantly longer time to complete their migration from BON to LGR, than did inriver fish.
- Anecdotally, 18 individuals in our tag set were known to have strayed (inclusive of hatchery and wild groups) to the Mid-Columbia River, based on detections at adult ladders at Priest Rapids, Rock Island, and Wells dams. The majority of these individuals (13/18) were transported as juveniles.
- Though our analysis demonstrates a clear effect of juvenile outmigration history on the homing success of both hatchery and wild adult summer steelhead, some limitations/caveats worth noting include: i) because adult detection capabilities are absent from most tributaries receiving strays, our stray estimate likely underestimates the actual stray rate; ii) too few above-LGR (i.e., released in sub-basins with fish of known race type) tags were available for a race-level (i.e., 'A' vs. 'B') delineation of transportation effects.

Dataset overview and analysis methods

To address your steelhead transportation-effects analysis request, we constructed a dataset containing the interrogation histories of all steelhead (hatchery and wild, to bolster sample sizes) that were i) PIT tagged as juveniles and of Snake River origin (i.e., from above LGR); and ii) detected on a Bonneville Dam (BON) fish ladder as an adult in return years 2001-2005. Due to the small number of records available for the analysis, we drew on records for individuals tagged at trap, tributary, and hatchery sites, as well as those marked at LGR as part of NOAA-Fisheries' transportation study (e.g., Marsh et al. 2005). Individual fish were classified as being transported as juveniles based on their interrogation details in bypass systems at transportation sites; fish undetected as smolts and those detected at transportation sites, but routed back to the Snake River (via bypass) were classified as members of an 'inriver' group. Using these data (**Table 1**), we quantified and compared between transport and inriver groups several measures related to adult steelhead homing behavior and upstream migration success:

<u>*Survival and homing success.*</u>--For the first step of our analysis, we evaluated whether or not there was a systematic difference in the homing success of adult steelhead of different outmigration histories. Thus, all returning adults were classified as failing or succeeding in their BON-LGR migration based on their detection status at LGR (i.e., seen = success; unseen = failure). In our analysis, homing success is taken as being equivalent to apparent BON-LGR survival and therefore includes losses due to straying, harvest, and other mortality agents. Assuming that the latter two causes of fish loss affect transported and inriver groups similarly, it can be inferred that a measurable portion of any survival difference observed is likely due to a straying component.

We compared the homing success of transported and inriver histories in three ways, for each wild and hatchery steelhead *separately*. First, we graphically compared the overall proportion of successful upstream migrants between transported and inriver groups. Second, we statistically tested whether or not homing success or failure was independent of outmigration history using χ^2 tests, on both a year-by-year (migration and return years, separately) and pooled basis. Finally, we tested for an influence of outmigration history and river conditions on homing success using logistic regression. In particular, we modeled the binary response (success or failure) as a function of the continuous environmental variables water temperature and discharge (both indexed at BON based on an individual's arrival date[2]), as well as a dummy variable characterizing outmigration history.

Migration characteristics.--For the second part of our analysis, we compared adult return timing (BON detection dates, *for all returning adults*) and upstream migration rates (BON-LGR travel times, *for successful migrants only*) between outmigration histories, as both of these migration characteristics are likely to be influenced by impaired homing behavior (e.g., greater rates of non-natal basin wandering increases travel times). We tested for an effect of outmigration history on return dates and migration rates, while accounting for return-year effects, using a two-way analysis of variance (ANOVA, factors: outmigration history [inriver, transport], return year [2001-2005], and their interaction).

Non-natal basin stray rates.--Finally, using all available PIT-tag detections reported in PTAGIS (i.e., all mainstem dam and tributary 'obs' sites, as well as reported recoveries—mortalities or otherwise), we estimated a stray rate (defined as a detection at non-natal basin facilities, independent of ultimate LGR-detection fate) for adults contained in our dataset. It should be noted that the overall PIT-tag recovery effort present in the basin is likely inadequate to estimate a 'true' straying rate (e.g., the majority of sub-basins to which steelhead have the opportunity to stray into lack passive detection sites). As the estimates computed for this memo should are likely gross underestimates of actual stray rates, they should be taken primarily as a validation of inferences made based on other migration characteristics.

Findings and general conclusions

Based on a combination of behavioral and demographic parameters, we summarize below several lines of evidence demonstrating the existence of a non-trivial effect of juvenile transportation history on the homing ability of hatchery and wild adult summer steelhead. Briefly, we will show that transported fish return the Lower Columbia River later, take longer to travel from BON to LGR during their upstream migration, have lower homing success rates, and have higher documented stray rates, compared to inriver outmigrants.

Survival and homing success.--Overall, we found that about 80% of all steelhead detected at BON arrived (i.e., survived) upstream for detection at LGR. However, the probability of an individual migrating successfully from BON to LGR was less for transported than inriver steelhead (**Tables 2 and 3**; **Figure 1**). For both hatchery and wild groups, adults that were transported as juveniles survived their migration from BON to LGR at a ~10% lower rate than their inriver counterparts. Despite some inter-annual variability, the pattern of lower upstream-migration success for transported relative to inriver fish was evident for

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[2] Given that the majority (88%) of fish that failed in their BON-LGR migration dropped out before reaching McNary Dam, we modeled river conditions for the Lower Columbia River only.

hatchery and wild steelhead and for both migration and return year-based groupings. Further, χ^2 tests indicate that the observed differences were statistically significant (or nearly so) in most years, and on a total-sample basis (**Table 3**); this was particularly true for wild steelhead. Finally, though not presented herein, we also assessed differences on tag-site basis (i.e., decomposed into LGR and above-LGR groups described in **Table 1**). Though fewer of these tests were statistically significant, the trend towards reduced survival for transported fish prevailed.

In addition to our χ^2 analysis, we also fit logistic regression models predicting homing success as a function of outmigration history, river temperatures, and discharge (**Table 4**). For both hatchery and wild steelhead models, the outmigration history parameter was a significant predictor of homing success ($P < 0.05$ for both). Further, individual inriver fish were more likely to survive to LGR than those that were transported previously (inriver:transport odds ratios, 95% CI: hatchery -- 1.6, 1.2-2.1; wild -- 1.7, 1.5-2.0). With respect to environmental conditions, wild steelhead homing success was significantly (negatively) affected by flow and (positively) by temperature; though non-significant ($P > 0.4$ both), hatchery-model temperature and discharge slope parameters were similar to those fitted for wild steelhead. Thus, some portion of return year-specific variability in homing success was due to environmental conditions present in the Lower Columbia River.

Migration characteristics.--Similar to homing success patterns, return timing and travel time patterns similarly suggest an effect of transportation on the expression of straying behavior by returning adult steelhead. For hatchery steelhead, BON return dates were significantly later and BON-LGR travel times longer for fish of transported compared to inriver histories (**Tables 5 and 6**). Though there was some return-year variance in the difference between groups, on average transported hatchery steelhead returned on August 25th whereas inriver fish returned on the 19th (**Figure 2**). At 40 days on average, transported hatchery adults typically took ~4 days longer to travel from BON to LGR than their inriver counterparts (**Figure 3**).

In contrast to hatchery steelhead, we found little evidence indicating a systematic effect of transportation on wild steelhead return timing (**Tables 5 and 6**). In some years wild transported fish returned earlier and other years later than inriver outmigrants (**Table 5**), with both groups having a similar overall average return date (August 10th and 11th for transport and inriver groups, respectively; **Figure 2**). In contrast, we did observe a significant influence of outmigration history on upstream migration rates. That is, wild adult steelhead that were transported as juveniles took approximately seven days more than inriver fish to complete their migration from BON to LGR (**Figure 3**).

Non-natal basin stray rates.--The increase in straying behavior due to juvenile transportation, as implied by the homing success rate, travel time, and return date patterns described above, was anecdotally confirmed by actual stray documentation available for individuals in our tag set. Based on a query of Mid-Columbia dam adult detection records, as well as PIT-tag recovery and mortality databases, we documented straying behavior for both hatchery and wild steelhead tagged at and above LGR in four of five migration years (2002-2005), totaling 18 confirmed strays (**Table 6**). Of these individuals, the majority (13/18) were wild, which also constituted the majority of our original tag set; also, 13/18 (73%) of these individuals were of transport origin. Across 2002-2005 (years where straying was documented in our dataset), we estimated a stray rate of 0.45% overall and 1.0-1.5% for transported fish. Again, it needs to be emphasized that these are minimum estimates of pre-LGR straying levels, given the limited coverage of PIT-tag recovery efforts available for estimating actual stray rates.

Implications, limitations, and future work

Based on this analysis, it appears that inter-basin straying by Snake River steelhead is measurably influenced by the smolt transportation program. As hypothesized previously (Berggren et al. 2006; Keefer et al. 2006), this is likely due to a disruptive effect of collection and rapid downstream transportation on the natal-basin imprinting process, which out-migrating pre-smolts are assumedly undertaking (e.g., Pascual et al. 1995; Bugert et al. 1997; Chapman et al. 1997). The management implications of this impact of transportation on the homing success of returning adult salmon and steelhead are many-fold, and at a minimum raise considerable concern about the genetic integrity of imperiled populations recipient to hatchery and wild strays of non-endemic stock origin (Keefer et al. 2006). The importance of this statement becomes even more apparent when considering the fact that the majority of run-at-large outmigrants are transported as juveniles (i.e., PIT-tagged fish are under-represented in the transportation program relative to the run at large).

Despite the apparent negative effects of juvenile transportation on adult homing and straying behavior described here, there are significant limitations with the steelhead tagging program as it presently exists that need to be acknowledged. In particular, the majority of wild and hatchery steelhead records used in our analysis (60%) were tagged at two sites (Lower Granite Dam and the Snake River Trap) where race (i.e., A vs. B) cannot be discerned (i.e., as opposed to basin-specific marking efforts where the local race is known). Thus, whether or not transportation effects are confounded with race effects (e.g., differing exposures to the transportation program due to differing outmigration timing patterns) is not amenable to robust evaluation at the present time. Enhanced hatchery- and basin-specific hatchery and wild tagging—at levels similar to those presently attained through the combined CSS and SMP efforts for spring/summer Chinook salmon—will allow for a thorough resolution of this issue. Given the convergence of multiple measures and studies (ours and Keefer et al.'s), as well as our previous documentation of a similar transport effect on spring/summer Chinook salmon, however, we preliminarily conclude that transportation affects steelhead straying.

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Table 1. Sample sizes for hatchery and wild summer steelhead groups, by return year and tag location. 'Above-LGR' includes all hatchery and wild adults that were tagged and released upstream of Lower Granite Dam (i.e., SMP, tributary marking, etc.). 'LGR' fish are those tagged at Lower Granite Dam as part of NOAA's transportation study. To maximize sample sizes, we combined both Above-LGR and LGR fish for our analysis.

Origin	Return year	Above-LGR	LGR	Total
hatchery	2001	182	365	547
	2002	123	96	219
	2003	132	130	262
	2004	173	123	296
	2005	139	63	202
wild	2001	134	1,075	1,209
	2002	176	1,370	1,546
	2003	115	714	829
	2004	134	512	646
	2005	127	267	394

Table 2. Apparent BON-LGR survival estimates for inriver ('I') and transported ('T') outmigrant hatchery and wild steelhead, by migration year, return year, and across the pooled tag set. Note: data are not presented for MY2001, due to the small number of fish for study groups. Also, inference was restricted to those years where both I and T groups had a minimum of 15 adults detected at LGR initially (i.e., '.' denotes that insufficient data were available).

		hatchery				**wild**			
	Year	***n***	**I**	***n***	**T**	***n***	**I**	***n***	**T**
Migration Year	2000	429	0.77	56	0.64	1,119	0.81	1,283	0.71
	2002	.	.	.	.	489	0.77	553	0.69
	2003	209	0.81	109	0.79	201	0.82	255	0.75
Return Year	2001	392	0.76	155	0.63	574	0.85	635	0.69
	2002	176	0.75	43	0.70	578	0.77	968	0.70
	2003	242	0.82	20	0.65	213	0.79	616	0.71
	2004	235	0.80	61	0.82	199	0.53	447	0.73
	2005	136	0.82	66	0.79	88	0.81	306	0.74
	All tags	1,181	0.79	345	0.70	1,652	0.81	2,975	0.71

Table 3. χ^2 test results evaluating independence between juvenile outmigration history (transported vs. inriver) and apparent BON-LGR survival (i.e., success vs. failure), by MY, RY, and rearing type (hatchery vs. wild). Bold-faced test statistics and *P*-values indicate a significant association between juvenile transport history and upstream migration success at $\alpha = 0.05$; underlined values were deemed significant at $\alpha = 0.10$ (*for this table and those hereafter*). 'na' denotes that a particular test could not be performed due to low cell frequencies (i.e., < 5). Note: tests were not done for MY2001, due to the small number of inriver fish.

		hatchery		wild	
Grouping	**Year**	χ^2	***P*-value**	χ^2	***P*-value**
Migration Year	**2000**	**4.272**	**0.039**	**33.398**	**0.000**
	2002	na	na	**16.786**	**0.000**
	2003	0.251	0.616	2.771	0.096
Return Year	2001	**10.424**	**0.001**	**40.201**	**0.000**
	2002	0.491	0.483	**10.026**	**0.002**
	2003	3.552	0.059	**6.094**	**0.014**
	2004	0.174	0.677	**8.661**	**0.003**
	2005	0.228	0.633	1.566	0.211
	All	**10.615**	**0.001**	**59.490**	**0.000**

Table 4. Logistic regression parameter estimates and statistical tests.

Origin	Parameter	Estimate	SE	*t*	*P*-value
hatchery	Intercept	0.357	0.843	0.42	0.672
	Outmigration history	**0.447**	**0.139**	**3.23**	**0.001**
	Temperature	0.033	0.042	0.78	0.434
	Discharge	-0.001	0.002	-0.82	0.411
wild	Intercept	0.262	0.451	0.58	0.562
	Outmigration history	**0.555**	**0.075**	**7.38**	**0.000**
	Temperature	**0.047**	**0.022**	**2.18**	**0.029**
	Discharge	**-0.002**	**0.001**	**-2.99**	**0.003**

Table 5. Analysis of variance (ANOVA) results for a comparison of Bonneville Dam arrival dates between outmigration histories across available return years.

Origin	Source	SS	df	MS	*F*-ratio	*P*-value
hatchery	**Outmigration history**	**5,940**	**1**	**5,940**	**9.742**	**0.002**
	Return year	**6,428**	**4**	**1,607**	**2.636**	**0.033**
	OH x RY	**5,985**	**4**	**1,496**	**2.454**	**0.044**
	Error	924,253	1,516	610		
wild	Outmigration history	425	1	425	0.601	0.438
	Return year	**135,321**	**4**	**33,830**	**47.833**	**0.000**
	OH x RY	**8,420**	**4**	**2,105**	**2.976**	**0.018**
	Error	3,263,291	4,614	707		

Table 6. ANOVA results for a comparison of Bonneville-to-Lower-Granite travel times (in days, log transformed) between outmigration histories across available return years.

Origin	Source	SS	df	MS	*F*-ratio	*P*-value
hatchery	Outmigration history	1.1	1	1.12	3.233	0.072
	Return year	**15.5**	**4**	**3.88**	**11.239**	**0.000**
	OH x RY	2.4	4	0.59	1.714	0.144
	Error	400.5	1159	0.35		
wild	**Outmigration history**	**14.4**	**1**	**14.40**	**25.622**	**0.000**
	Return year	**30.3**	**4**	**7.57**	**13.467**	**0.000**
	OH x RY	**6.8**	**4**	**1.70**	**3.028**	**0.017**
	Error	1,923.83	3,423	0.56		

Table 7. 'Stray' steelhead of Snake River origin (tagged at or above LGR) detected at mid-Columbia River adult ladders (PRD = Priest Rapids Dam; RIS = Rock Island Dam; WEL = Wells Dam). 'ND' = not detected.

PIT-tag ID	Return year	Origin	Tag site	History	PRD	RIS	WEL	Home to LGR?
3D9.1BF0F2C528	2002	hatchery	LGR	transport	ND	ND	23-Oct	fail
3D9.1BF11EB929	2003	hatchery	Grande Ronde River	transport	7-Aug	ND	18-Aug	fail
3D9.1BF18224BC	2004	hatchery	Lemhi River	transport	7-Sep	ND	ND	success
3D9.1BF1B3A3C9	2005	hatchery	Imnaha River	inriver	29-Jul	ND	ND	success
3D9.1BF1C43EB4	2005	hatchery	LGR	inriver	11-Aug	16-Aug	29-Aug	success
3D9.1BF0FEDA01	2002	wild	LGR	inriver	ND	ND	10-Nov	fail
3D9.1BF1059801	2002	wild	LGR	transport	ND	ND	6-Oct	fail
3D9.1BF1093012	2002	wild	LGR	transport	ND	ND	24-Sep	fail
3D9.1BF10E7031	2003	wild	Squaw Creek	inriver	27-Jul	ND	ND	fail
3D9.1BF11D172A	2003	wild	LGR	transport	7-Aug	ND	29-Aug	success
3D9.1BF11D309E	2003	wild	LGR	transport	1-Aug	ND	ND	success
3D9.1BF11DA75E	2003	wild	LGR	transport	4-Aug	ND	ND	success
3D9.1BF1121146	2004	wild	LGR	inriver	3-Aug	ND	ND	success
3D9.1BF11CB93C	2004	wild	LGR	transport	23-Aug	1-Sep	10-Sep	fail
3D9.1BF11DA9BD	2004	wild	LGR	transport	25-Jul	ND	ND	success
3D9.1BF11E0B0C	2004	wild	LGR	transport	25-Aug	6-Sep	ND	success
3D9.1BF130D8EB	2005	wild	Lookingglass Creek	transport	20-Sep	ND	ND	fail
3D9.1BF1BE78B5	2005	wild	LGR	transport	4-Aug	ND	ND	success

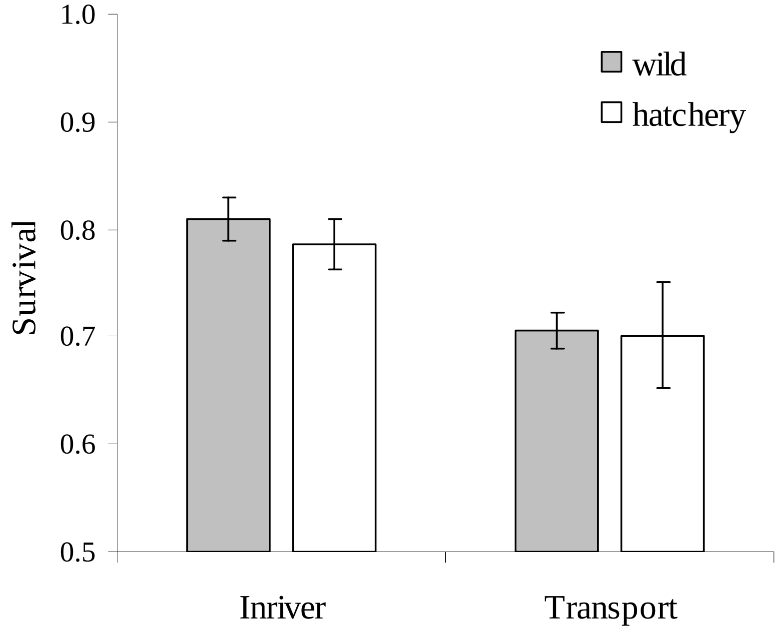

Figure 1. Overall estimates of wild and hatchery summer steelhead homing success (+/- 2 SE), by out-migration history, for return years 2001-2005.

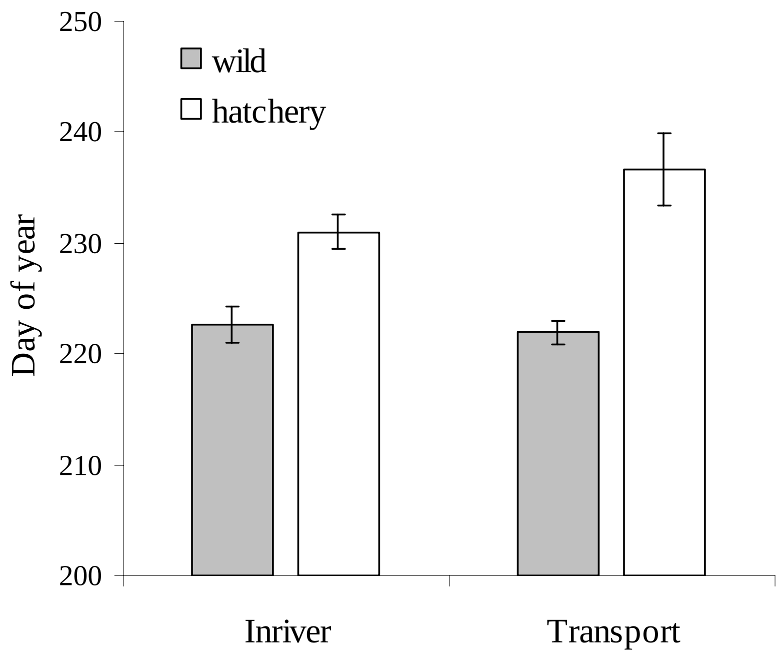

Figure 2. Least-squares mean (+/- 2 SE) Bonneville Dam return dates for wild and hatchery summer steelhead, by out-migration history, for return years 2001-2005 (Note: day 200 = 19 July, day 250 = 7 September).

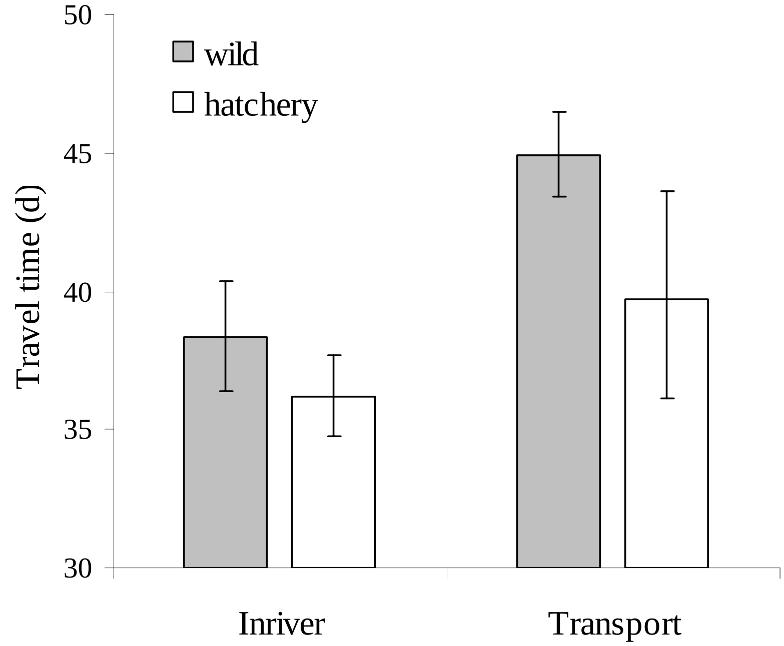

Figure 3. Least-squares mean (+/- 2 SE) Bonneville-to-Lower Granite travel times for wild and hatchery summer steelhead, by out-migration history, for return years 2001-2005.