INTERSPECIFIC DIFFERENCES IN SALMONID POPULATION RESPONSES TO DAM PASSAGE MEASURES IN THE UPPER WILLAMETTE RIVER BASIN

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Juvenile spring Chinook salmon (*Oncorhynchus tshawytscha*) and winter steelhead (*O. mykiss*) rear in streams below and above Upper Willamette River (UWR) reservoirs. UWR populations of both species have been listed as threatened under the ESA, culminating in legal requirements to implement dam passage measures (DPMs) to improve juvenile survival rates during downstream migration of these two species. It has been of interest to evaluate alternative suites of candidate measures for ten dams in the Upper Willamette River (see Table 1 for examples of these). Research in the region has enabled the computation using Fish Benefits Workbook Software (FBW, Alden BioAnalysts Inc. 2014) of dam passage efficiency (DPE) and survival rates (DPS) for juveniles of both species at different life stages under different dam passage and operation measures for dams in the UWR. However, evaluations of the effectiveness of dam passage measures have been required to consider also long-term expected population outcomes according to performance metrics (PMs) like quasi-extinction risk, population productivity and average abundance of natural origin spawners above the dams. Life cycle models (LCMs) (e.g., McAllister et al. 2022a) have recently been developed to use outputs from FBW to compute these PMs for above dam populations of each of these two species under specific sets of passage measures (DPMs) (Tables 1 and 2, Figures 1 and 2). While the PMs will be partly determined by the inputted DPE and DPS, life cycle modeling has shown that the calculated PMs from LCMs are not predictable a priori based on DPE and DPS outputs from FBW (McAllister et al. 2022a). While the determination of whether a DPM may be acceptable and how to rank alternative DPMs involves consideration of numerous variables, this talk focuses primarily on interpretation of fish population performance metrics when there are two or more species of interest.

Although there are similarities in the population status and life histories of steelhead and Chinook salmon, there are also differences that make it unclear whether the their UWR populations will respond similarly to alternative DPMs. For example, spring Chinook salmon die after spawning and have several different freshwater juvenile migrant types. In contrast, winter steelhead can spawn more than once and have a single dominant freshwater juvenile migrant type in the UWR. In this talk, we (1) demonstrate how fish population responses to alternative DPMs predicted by LCMs and the ranking of dam passage measures based on calculated PMs can differ between these two species in the UWR, (2) highlight potential trade-offs in PMs between DPMs for these two species and (3) identify potential mitigative actions

that could be considered should LCMs predict that none of the alternative DPMs considered will perform satisfactorily for both species.

We initially consider a common decision analysis criterion, i.e., ranking of actions according to their expected utility. The utility function for each PM for each species could be made directly proportional to the PM for the species, where in terms of conservation gains, the highest value for long-term average spawners (LTS) and lowest probability of quasi extinction (PQE) have the highest utilities. We will ignore for now other performance metrics as these tended to be strongly correlated with the two considered here.

Results

Generally, alternative DPMs that included either spring spill (SS), fall drawdown (FD), or spring drawdown (SD) performed more poorly than those that included either a floating screen structure (FSS) or floating surface collector (FSC) for both species (Tables 4 and 5). However, the ranking of alternatives based on LTS and PQE differed between the two species. For example, DPM3 included FSSs on the Detroit and Cougar Dams, an FSC on Lookout Point, a modified weir (MW) on Foster, and SS and FD on Green Peter Dam (Table 1). For spring Chinook salmon, DPM3 performed consistently well and gave among the lowest PQE (though as high as 0.56 for the Middle Fork) and among the highest LTS (i.e., at 366 fish for the Middle Fork and as high as 13,083 fish for the North Santiam) (Table 4).

In contrast, DPM1 ranked highest of the alternatives evaluated for winter steelhead (Table 5). DPM1 included a MW on Foster, an FSS on Green Peter in the South Santiam, and an FSS on Detroit in the North Santiam (Table 1). Compared to other alternatives, the LTA of steelhead adults was the highest under DPM1 on the South Santiam (at 568) and at close to highest on the North Santiam (at 780) (Table 5). PQE was among the lowest for DPM1 on the North Santiam (0.39) and the lowest on the South Santiam (though still relatively high at 0.65). In contrast, in the South Santiam under DPM3, LTA of steelhead spawners was much lower at 284 fish and PQE was much higher (0.83) than these were for DPM1 (Table 5). For Chinook salmon, DPM1 performed poorly in the both McKenzie—where no new passage measure is implemented—and in the Middle Fork following addition of an FSS. In these sub-basins under DPM1, the LCM predicted very high PQE for Chinook salmon (i.e., 1 and 0.98, respectively) (Table 4).

Thus, the alternative that ranked highest for steelhead had very poor results for Chinook salmon in two of the four sub-basins and the alternative that ranked highest for spring Chinook salmon gave very poor results in one of the two sub-basins for steelhead. Given that a single DPM which has a specific suite of measures for all 10 dams in the UWR needs to be chosen, this results in a direct trade-off between a DPM with much better results for steelhead and poor results for Chinook salmon versus a different DPM with much better results for Chinook salmon and poor results for steelhead. In public decision-making situations, it is common for decisions to involve stark trade-offs and considerable attention has been given to how to address trade-offs (see Keeny and Raiffa 1976; Lane and Stephenson 1998; Edwards and Dankel 2016). Initial

questions about the trade-offs should include: How certain is the difference in outcomes between alternatives? If it appears to be certain, could additional policy measures be identified that would reduce the severity of the outcomes to make them acceptable? If none can be formulated, and these are the only alternative actions available, then what approach could be taken to weigh the alternatives? We first address this latter question.

Decision analysis approaches that could be considered include a Maximin criterion, in which the decision maker chooses the action that has the least-worst consequence across the alternative scenarios posed. In this case Maximin would select DPM3 since the highest PQE under DPM3 is lower than that for the other DPMs, at 83% for steelhead (Table 5). Under DPM1 the highest PQE is 100% for Chinook salmon in the McKenzie and 98% for Chinook salmon in the Middle Fork (Table 4) making the worst outcome from DPM1 much worse than that under DPM3. An alternative decision criterion, the maximax approach, chooses the Alternative that gives the best of the best possible outcomes. The Maximax choice would be to choose DPM3 also, which had the best set of outcomes for Chinook salmon. However, given the severe outcomes for steelhead under DPM3, the gravity of the expected outcomes may still be unacceptable, especially as steelhead is also an EIS-listed species.

A yet third criterion, minimax regret, uses a rule that minimizes potential regret (where regret is experienced after the decision is made, measured as the degree to which you find you would have been better off with a different decision). Regret here could be assessed for each alternative and species considering the four sub-basins. For example, under DPM3 for spring Chinook salmon, how much better are the other alternatives? As none of the five other alternatives gave consistently much better results, the regret under DPM3 is relatively low for Chinook salmon (Table 4). But for winter steelhead under DPM3, where LTS was 284, we have a better result under DPM1 in the South Santiam with 568 spawners (Table 5). In terms of LTS, the regret would thus be 568-284 spawners = 284 spawners, and this is the maximum regret associated with DPM3. For DPM1 and Chinook salmon in the McKenzie, the LTS is 44 when it could have been 590 under DPM3 (Table 4). The regret under DPM1 in the McKenzie sub-basin would thus be large at 590 – 44 spawners = 556 spawners (Table 4). DPM1 would give on average 780 steelhead LTS on the North Santiam; DPM3 would have given on average 873 steelhead LTS on the North Santiam (Table 5). The regret for DPM1 and steelhead would be the average difference of 93 steelhead spawners (Table 5). Thus, the maximum regret associated with DPM1 is 556 Chinook salmon spawners which is greater than the maximum regret under DPM3. In this case the minimax regret alternative would be DPM3. Thus, the three alternative decision analysis criteria, Minimax, Maximax and Minimax regret, would rank DPM3 highest.

It could be determined that selecting an alternative with an PQE as high as 83% for one of the two species is unacceptable, and some additional measures could be required to reduce PQE for steelhead in the South Santiam. With the product of DPS and DPE at 0.505 for winter steelhead under DPM3 in the South Santiam (Table 5), there appears to be room for improvement in Dam Passage for winter steelhead on the South Santiam. For example, if it were possible to build an

FSS at Green Peter (otherwise maintaining measures prescribed under DPM3), this could increase DPS and DPE, and reduce steelhead PQE to less than 83% (like that expected under DPM1, Table 5). However, the PQE, e.g., if it were e.g., 65% could still be unacceptably high.

As natural origin (NOR) adult winter steelhead abundance returning to the Foster Dam tailrace in the South Santiam has been recently very low (i.e., on average <100 females per year 2017-2021), translocation of NOR winter steelhead from river reaches below to above the Foster Dam could be an additional measure that could help to reduce the risk of extinction in the above dam population. We conducted further analysis to support the Biological Assessment (BA) and considered an option to actively translocate winter steelhead to above Foster Dam. This reduced the PQE to 55% under the so-called Preferred Alternative (McAllister et al. 2022b).

There is currently no deliberate measure to improve downstream dam passage survival rates of kelts in the UWR. However, sensitivity analyses showed that improved survival rates of steelhead following spawning could significantly improve performance metrics, for example, with PQE dropping to 0.51 under higher values for repeat spawner survival rates (McAllister et al. 2022a). Measures to improve dam passage and downstream survival of kelts could potentially be instrumental in this (see Hatch et al. 2013).

Sensitivity analyses conducted in the EIS suggested that with higher marine survival rates, the performance metrics for steelhead could improve considerably (McAllister, et al. 2022a) (Fig. 3). While it is not possible to directly alter average future marine survival rates for winter steelhead, increased control of predator populations that impact the smolt to adult return rates for winter steelhead and spring Chinook salmon could potentially make a difference. For example, if measures recently approved to lethally remove sea lions in the lower Columbia River (https://www.nwp.usace.army.mil/environment/sea-lions/) were consistently applied in future years, this could help to increase smolt-adult return rates for both species in the UWR, further reduce PQE and make one or more of the Alternative DPMs considered more acceptable.

Figure 1. Representation of the spring run Chinook salmon life cycle model for above dam populations in the Upper Willamette River (McAllister et al. 2022a).

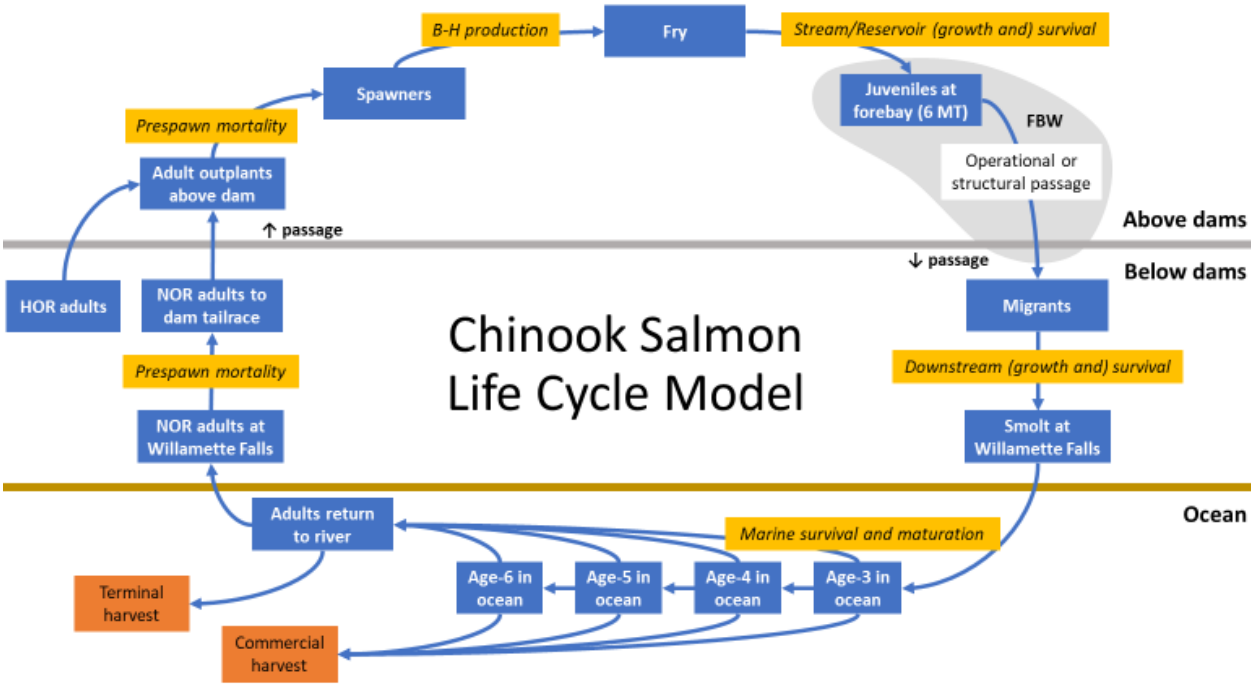

Figure 2. Representation of the winter steelhead life cycle model for above dam populations in the Upper Willamette River (McAllister et al. 2022a). FBW = Fish Benefits Workbook.

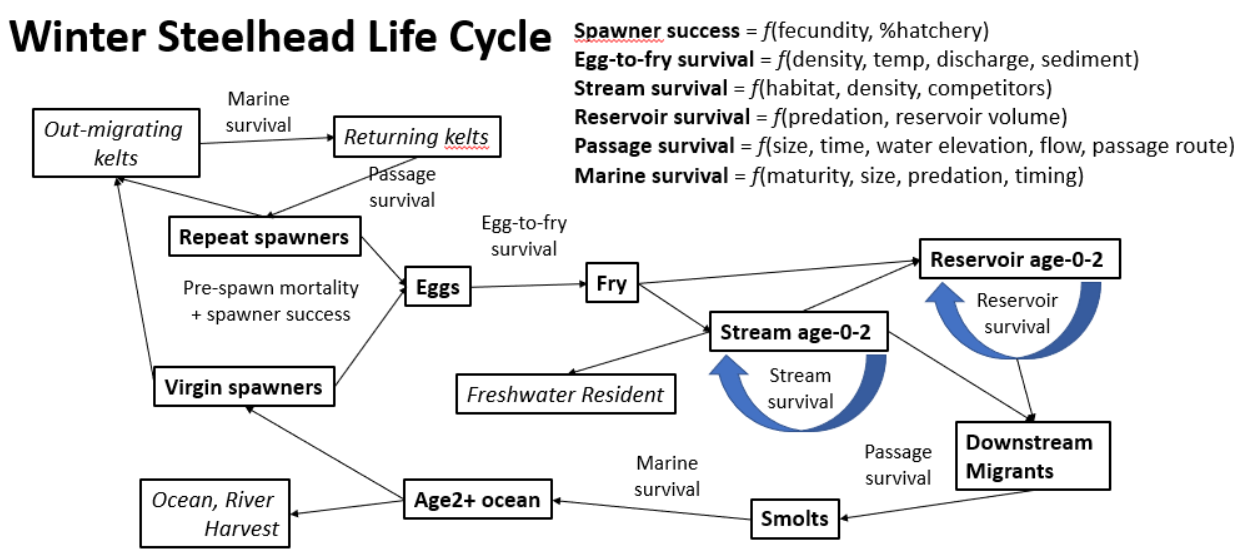

Figure 3. Isopleth of Foster spawner abundance across a range of marine survival and dam passage rates. The horizontal lines show the mean DPE*DPS for the different EIS alternatives (taken from McAllister et al. 2022a). Marine survival scaling was applied to the mean marine survival rate in projections of the steelhead LCM.

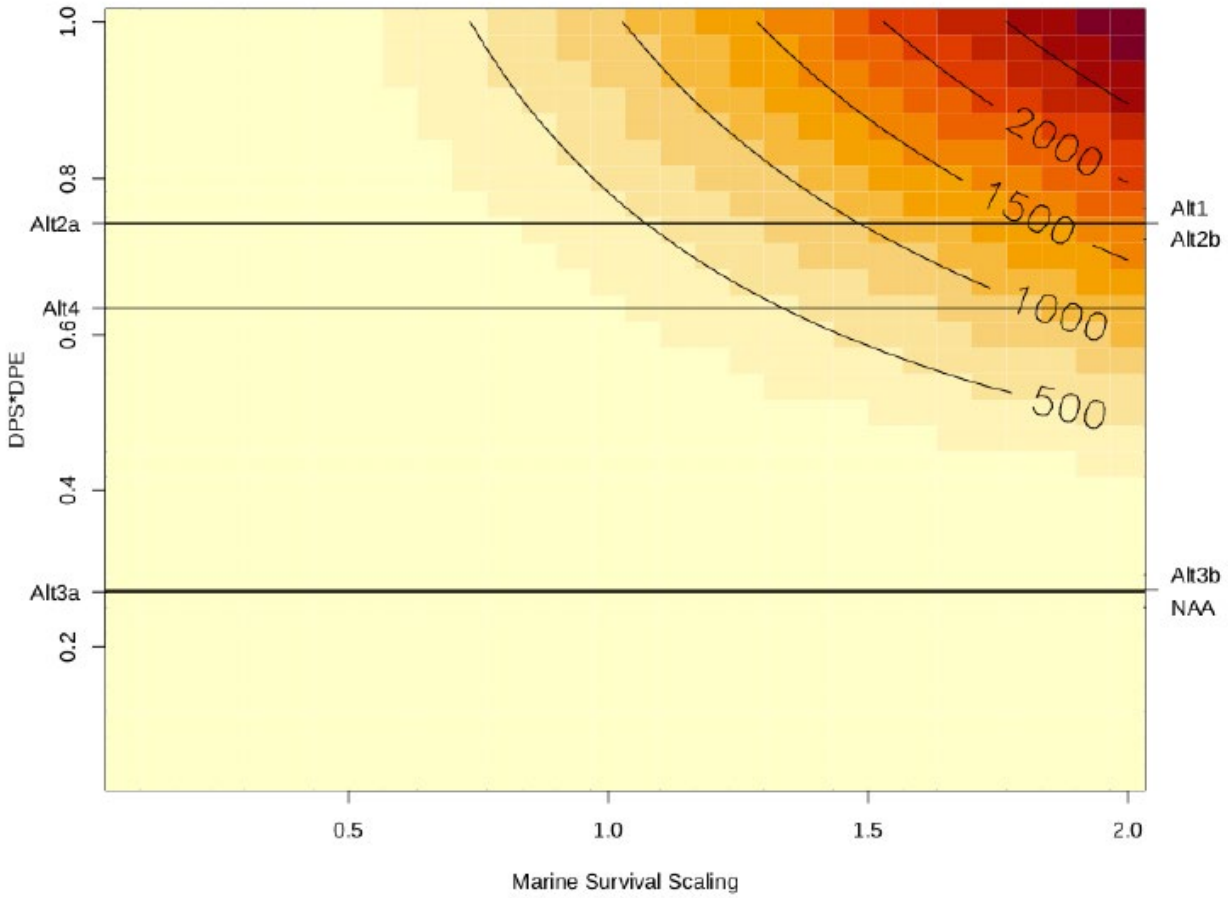

Table 1. Summary of downstream passage measures by alternative dam passage measure and dam project. Blank cells indicate no change to current measures. NAA=no action alternative, DPM=alternative, FSS=Floating Screen Structure, FSC=Floating Surface Collector, MW=Modified Fish Weir, SS=Spring Spill, SD=Spring Drawdown, FD=Fall Drawdown. Drawdowns to regulating outlets (RO) unless diversion tunnel (DT) specified. DET = Detroit, BCL = Big Cliff, FOS = Foster, GPR = Green Peter, CGR = Cougar, LOP = Lookout Point, DEX = Dexter, HCR = Hills Creek.

		EIS alternative						
Sub-basin	**Dam**	**NAA**	**DPM 1**	**DPM 2**	**DPM 3**	**DPM 4**	**DPM 5**	**DPM 6**
North Santiam	DET		FSS	FSS	FSS	SD FD	SS FD	FSS
	BCL		Collect at DET	Collect at DET	Collect at DET	SS	SS	Collect at DET
South Santiam	FOS		MW	MW	MW			MW
	GPR		FSS	SS FD	SS FD	SS FD	SD FD	
McKenzie	CGR			FSS	SD (DT) FD (DT)	SD FD	SD (DT) FD (DT)	FSS
Middle Fork	LOP		FSS	FSC	FSC	SD FD	SS FD	FSS
	DEX					SS	SS	
	HCR					SS FD	SD FD	FSC

Table 2. Definition of performance metrics (PM) computed from the Chinook salmon life cycle model given a 30-year management horizon. PMs were calculated from 10,000 simulation runs, following removal of a 5-year burn-in. R/S = Recruits-per-spawner; SAR = smolt-adult return rate, pHOS = proportion of hatchery-origin spawners; P(NOR) < QET = probability that NOR returns are less than the Quasi-Extinction Threshold (QET). Note that the median across simulations was used as a summary statistic for each PM apart from P(NOR) < QET, which used the mean across simulations.

Performance Metric	**Description**	**Statistic**
Abundance	NOR spawners	Geometric mean of year 16-30
Productivity	R/S SAR Fry-smolt survival	Geometric mean of year 1-5 Mean of year 1-5 Mean of year 1-5
Extinction risk	P(NOR) < QET	4-yr mean, year 16-30

Diversity	pHOS	Mean of year 26-30
	% migrant type smolts	Year 26-30
	% migrant type adult returns	Year 26-30
	Migrant type SAR	Mean of year 26-30

Table 3. Definition of performance metrics (PM) computed from the winter steelhead LCM given a 30-year management horizon. PMs were calculated from 10,000 simulation runs, following removal of a 2-year burn-in. R/S = Recruits-per-spawner; SAR = smolt-adult return rate; P(NOR) < QET = probability of NOR spawners below the Quasi-Extinction Threshold (QET). R/S start year is associated with age-4 recruits, SAR start year is associated with age-2 smolts. The median across simulations was used as a summary statistic for the PM apart from P(NOR) < QET, which used the mean across simulations.

Performance Metric	**Description**	**Statistic**
Abundance	NOR spawners	Geometric mean of year 16-30
Productivity	R/S	Geometric mean of year 1-5
	SAR	Mean of year 1-5
Extinction risk	P(NOR) < QET	4-yr mean, year 16-30
Diversity	None evaluated	

Table 4. Performance metrics for Spring Chinook Salmon in four UWR Sub-basins (McAllister et al. 2022a). See Table 1 for a definition of the acronyms of the dam passage measures and dam projects. See Table 2 for the definitions of the performance metrics. Red shading indicates poor performance, yellow indicates intermediate and green indicates the best performance.

McKenzie	**DPM 1**	**DPM 2**	**DPM 3**	**DPM 4**	**DPM 5**	**DPM 6**	**NAA**
		FSS	**SS, FD**	**SS,FD**	**SS, FD**	**SD, FD**	
NOR spawners	44	590	291	108	220	582	56
R/S	1.039	1.352	1.206	1.086	1.163	1.333	1.05
SAR	0.026	0.03	0.029	0.025	0.027	0.03	0.028
pHOS	0.905	0.193	0.475	0.771	0.577	0.197	0.879
P<QET	1	0.005	0.376	0.999	0.739	0.004	1
DPE	0.186	0.868	0.576	0.526	0.576	0.860	0.253
DPS	0.375	0.941	0.847	0.385	0.691	0.941	0.437
DPE*DPS	0.070	0.817	0.488	0.202	0.398	0.809	0.110

Middle Fork	**DPM 1**	**DPM 2**	**DPM 3**	**DPM 4**	**DPM 5**	**DPM 6**	**NAA**
	FSS	**FSC**	**FSC**	SD, FD	SS, FD	**FSS**	
NOR LOP spawners	182	366	350	95	107	336	118
NOR HC spawners	121	NA	NA	63	72	224	NA
R/S	1.149	1.237	1.247	1.076	1.108	1.245	1.09
SAR	0.011	0.012	0.012	0.011	0.011	0.011	0.011
pHOS LOP	0.848	0.742	0.746	0.911	0.903	0.754	0.889
pHOS HC	0.864	NA	NA	0.922	0.914	0.778	NA
P<QET	0.98	0.56	0.56	0.99	0.99	0.65	1
DPE (LOP)	0.824	0.824	0.824	0.555	0.668	0.962	0.617
DPS (LOP)	0.962	0.936	0.933	0.643	0.696	0.964	0.568
DPE*DPS (LOP)	0.793	0.771	0.769	0.357	0.465	0.927	0.350

North Santiam	**DPM 1**	**DPM 2**	**DPM 3**	**DPM 4**	**DPM 5**	**DPM 6**	**NAA**
DET	**FSS**	**FSS**	**FSS**	**SD, FD**	**SS, FD**	**FSS**	
BCL				**SS**	**SS**		
NOR spawners	12,530	13,083	13,016	7,710	5,923	12,720	963
R/S	2.057	2.047	2.072	1.855	1.655	2.05	1.057
SAR	0.072	0.07	0.072	0.078	0.078	0.071	0.068
pHOS	0	0	0	0	0	0	1
P<QET	0	0	0	0	0	0	0
DPE	0.782	0.850	0.849	0.705	0.617	0.795	0.491
DPS	0.954	0.959	0.960	0.725	0.704	0.960	0.617
DPE*DPS	0.746	0.815	0.816	0.511	0.434	0.763	0.303

South Santiam	**DPM 1**	**DPM 2**	**DPM 3**	**DPM 4**	**DPM 5**	**DPM 6**	**NAA**
FOS	**MW**	**MW**	**MW**			**MW**	
GPR	**FSS**	**SS, FD**	**SS, FD**	**SS, FD**	**SD, FD**		
NOR spawners (FOS)	1046	772	590	433	313	57	25
NOR spawners (GPR)	1295	963	728	535	386	NA	NA
R/S	1.564	1.5	1.411	1.32	1.243	0.755	0.643
SAR	0.056	0.056	0.055	0.053	0.052	0.042	0.039
pHOS (FOS)	0	0	0	0	0	0	0
pHOS (GPR)	0.385	0.427	0.474	0.536	0.607	NA	NA
P<QET	0.004	0.028	0.101	0.322	0.609	0.956	0.993
DPE (FOS)	0.761	0.810	0.761	0.761	0.761	0.761	0.761
DPS (FOS)	0.870	0.980	0.873	0.783	0.784	0.881	0.785
DPE*DPS (FOS)	0.662	0.794	0.665	0.596	0.597	0.671	0.597

Table 5. Performance metrics for Winter Steelhead in two UWR Sub-basins. See Table 1 for a definition of the acronyms of the dam passage measures and dam projects. See Table 3 for the definitions of the performance metrics. Red shading indicates poor performance, yellow indicates intermediate and green indicates the best performance. DPE = dam passage efficiency and DPS = Dam passage survival rate for 2-year old smolts.

North Santiam	**DPM 1**	**DPM 2**	**DPM 3**	**DPM 4**	**DPM 5**	**DPM 6**	**NAA**
Detroit	**FSS**	**FSS**	**FSS**	**SD, FD**	**SS, FD**	**FSS**	
Big Cliff				**SS**	**SS**		
Recruits Per Spawner (R/S)	1.648	1.721	1.721	1.042	0.725	1.678	0.534
NOR Spawners	780.1	872.6	872.6	208.9	96	817.7	21.7
P<QET Threshold	0.385	0.352	0.352	0.744	0.88	0.371	0.981
SAR	0.0422	0.0422	0.0422	0.0422	0.0422	0.0422	0.0422
DPS	0.86	0.869	0.869	0.758	0.649	0.869	0.528
DPE	0.824	0.846	0.846	0.647	0.627	0.828	0.587
DPS*DPE	0.727	0.756	0.756	0.492	0.419	0.739	0.315

South Santiam	**DPM 1**	**DPM 2**	**DPM 3**	**DPM 4**	**DPM 5**	**DPM 6**	**NAA**
Foster	**MW**	**MW**	**MW**			**MW**	
Green Peter	**FSS**	**SS, FD**	**SS, FD**	**SS, FD**	**SD, FD**		
Recruits Per Spawner (R/S)	1.496	1.11	1.108	0.667	0.523	1.144	0.506
NOR Spawners	567.6	284.1	283	42.1	18.7	159.3	8.6
P<QET Threshold	0.653	0.826	0.827	0.989	0.996	0.811	0.996
SAR	0.0422	0.0422	0.0422	0.0422	0.0422	0.0422	0.0422
DPS	0.864	0.775	0.773	0.677	0.761	0.777	0.682
DPE	0.77	0.65	0.649	0.524	0.436	0.723	0.47
DPS*DPE	0.679	0.505	0.503	0.354	0.321	0.567	0.319

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