Appendix C

Analyses to determine steelhead spawner abundance, returns, returns per spawner, and associated 12-year geometric means

Introduction

Reconstructing steelhead runs in the Upper Columbia ESU has been difficult in the past because of lack of spawning ground information, discrepancies between dam counts, and their complicated life histories. We have created a relatively simplified method that can more readily be used by researchers and regulators to determine the status of the population in terms of abundance (escapement) and productivity (returns per spawner).

Data Set

Dam counts

Since spawning ground counts are not available for a long time series for steelhead in the Upper Columbia, it is necessary to use dam counts, which go back to 1933 for Rock Island and 1962 and 1967 for Rocky Reach and Wells dams, respectively.

In examination of dam count differences (which could be a measure of tributary turn off between Rock Island, Rocky Reach, and Wells Dams), many problems arise. In some years, the fish count from the dam upstream was higher than the dam immediately downstream (this occurs primarily between Rocky Reach and Wells Dams).

Steelhead dam counts have been analyzed in different ways by different researchers. A common way to break down the counts is to use the "cycle count." This is the number of steelhead counted from June-November in year 1 and adding April and May in year 2 to get a total spawning brood. The assumption has been that this is a more accurate estimate of the brood year population; however, it may not be necessary and using annual counts may be as precise.

Chapman et al. (1994) looked at the percent passage of steelhead per month at Rock Island Dam between the 1930s and the 1980s (Figure 1). They found that the percentage of fish ascending the dams in April and May has decreased since the 1930s and 1940s. English et al. (2003) found that, in two years of research, about 13% of the steelhead (both hatchery and naturally produced, with most hatchery fish) over-wintered and stayed in the mainstem Columbia River between Priest Rapids and Chief Joseph dams (never ascended a tributary). Whether they spawned in any of these reaches has not been determined, but it does demonstrate another factor in the inaccuracy of using cycle counts to determine a particular year's spawning aggregate.

Finally, a comparison between cycle counts and regular calendar year (April – November) counts at Priest Rapids and Wells dams show little difference between cycle and calendar counts (Figures 2 and 3). Annual counts are more readily available, and we decided to use them instead of cycle counts in our analyses.

Separating the Entiat and Wenatchee Populations

Because of the difficulties mentioned above concerning the dam count differences between Rocky Reach and Wells Dams, Cooney et al. (2001) choose to combine the Entiat and

Wenatchee populations in their analyses. This causes problems in determining the health and listing status of the *independent* populations within the Wenatchee and Entiat Rivers. Therefore, a method was developed to separate these two populations.

The difference in the annual counts between Rock Island and Wells (fish passed upstream) were used as the basis for the analysis. This gave the total population between the two projects, where the Wenatchee (upstream of Rock Island) and Entiat (upstream of Rocky Reach) enter the Columbia River. English et al. (2001, 2003) found that of the naturally produced fish that over-wintered in the area between Rock Island and Wells dams, in the two years that they observed, an average of 9.5% (8.3-11.5%; based on a very small sample size) stayed in the Entiat and 74.3% in the Wenatchee (65.4-79.2%; Table 1). In lieu of comprehensive spawning ground counts, or tributary-specific counts (e.g., at a dam or weir), this was considered the best available information to determine the percentage of fish using each tributary. **In future years, as more data becomes available for spawning ground counts, this metric will be reevaluated.**

Separating the Methow and Okanogan Populations

The number of steelhead that ascended Wells Dam (after capture for broodstock) was used as the basis for the analysis. For naturally produced steelhead upstream of Wells, English et al. (2001, 2003) found that an average of 19.5% over-wintered in the Okanogan River (18.2-20.8%; sample size of 9) and 73.9% in the Methow (72.7-75.0%; Table 1). Using this information, the average percent was applied to the composite data sets to determine proportions of the runs to the tributaries between Rock Island and upstream from Wells.

Harvest

Harvest numbers were used from Chapman et al. (1994) or from updated information provided by WDFW. Harvest was applied equally to the composite populations for the Wenatchee/Entiat, or Upstream from Wells Dam (Methow/Okanogan). Fish harvested in the mainstem Columbia were added also (Rock Island-Wells Dams for Wenatchee/Entiat, and upstream from Wells for Methow/Okanogan).

The harvest on the naturally produced proportion of the run was assumed to be proportional to the total harvest (i.e., harvest rate was assumed equal between hatchery and naturally produced fish; if 100 fish were harvested and the naturally produced percentage of the total run was 25%, then 25 naturally produced fish were harvested). Beginning in 1986, after regulations began that restricted harvest on naturally produced fish, a 2% harvest rate was assumed for naturally produced fish (from catch and release).

Since 2002, recreation fishing has begun again upstream from Rocky Reach Dam. We maintained a 2% harvest rate on naturally produced fish, which may be conservative. No harvest is assumed in the Wenatchee/Entiat during this time frame since there are no targeted fisheries, although a very small number of naturally produced fish may be incidentally impacted between Rocky Reach and the mouth of the Entiat.

For all populations, a 10% pre-spawning mortality was assumed (and added to "harvest")

Naturally produced proportion of the run

The naturally produced proportion of the run has been estimated at Priest Rapids Dam since 1985 and Wells Dam since 1982. The percentage of naturally produced fish in the Wenatchee

River has been estimated by Brown (personal communication) and is based on the estimates from Priest Rapids and Wells Dams. To obtain proportions of naturally produced fish prior to 1982, values were estimated based on historical knowledge of when hatchery introductions began in earnest in the specific tributary in question (in general, hatchery returns began to dominate the runs in the late 1960s).

Age at return

Age at return was obtained from sampling efforts of naturally produced fish sampled at Priest Rapids (since 1986) and Wells (since 1982) dams. For years prior to these sampling efforts, an average was assumed.

Escapement

Escapement was estimated by first determining the appropriate aggregate run (between Rock Island and Wells or upstream of Wells). The naturally produced proportion was then extracted from the aggregate run. Harvest was then subtracted, and a 10% pre-spawning mortality was included into the harvest proportion. This resulted in an aggregate estimate of escapement. The proportion of fish to the appropriate tributary was then determined by applying the average percentages from the radio telemetry information (see above).

Return per spawner

The return per spawner was determined by taking the estimated escapement per tributary and multiplying it by the age of return, which gave a return of each age group per brood year. The return from a given spawning year was the summation of each appropriate age group (year 3 + year 4, etc., so returns for a given brood year are the summation of up to 5 or more years of returns). The returns per spawner was the quotient of the number of fish escaping in year x divided by the total returns for that brood year.

Reproductive success of hatchery fish

One of the greater unknowns concerning hatchery fish that spawn in the wild is how reproductively effective they are, both in terms of the number of offspring they produce and whether they are spawning in appropriate areas at the appropriate time.

Because of these concerns, two estimates of returns per spawner were calculated. One with the assumption that hatchery fish are as effective as naturally produced fish in terms of the number of returning adults, and the other, that they contribute nothing to the returning escapement. The truth is most likely somewhere in between, but the extremes are graphically shown.

For some years in the late 1970s and early 1980s, the returns per spawner were unrealistically high (> 10) and were omitted. These large estimates appear to be based on the extremely low number of naturally produced fish that escaped the fisheries in those years (almost zero).

Finally, it is important to note that the productivity (return/spawner) is very conservative since factors such as inter-dam loss and lower Columbia River fisheries are omitted from the analyses. The actual productivity of these steelhead runs is somewhat greater than shown here, but most likely would still not be great enough to reach de-listing criteria.

It is also important to reemphasize that this method should be reviewed and potentially modified as we begin to collect more tributary-specific information on steelhead from future monitoring and evaluation information.

Results

Wenatchee and Entiat Rivers

Between 1967 and 2003, an average of 761 naturally produced steelhead spawned in the Wenatchee River (range; 70-2,864; Table 2; Figure 4). In the Entiat River, spawning escapement has ranged from 9 to 366, averaging 97 fish (Table 2; Figure 5). The 12-year geometric mean of spawners in the Wenatchee River has ranged from 185 to 919, and is currently (2003) 716 (Table 2). For the Entiat River, the 12-year geometric mean has ranged from 24 to 118 and is currently 92 (Table 2).

The returning number of fish to both tributaries is auto-correlated since they were derived from the same aggregate. Therefore, the return per spawner is reported for both populations combined. In the Wenatchee and Entiat rivers, the return per spawner has averaged 1.42 (range; 0.13-4.73) if hatchery fish produce the equivalent number of returning spawners as naturally produced fish, and averages 0.28 (range; 0.05-0.79) if hatchery fish do not produce any returning spawners (Table 2; Figure 6). The 12-year geometric mean of the return per spawner has averaged 1.22 (range 0.71-1.96) if hatchery fish are equivalents to naturally produced fish, or 0.26 (0.18-0.32) if they do not contribute (Table 2; Figure 6).

Methow and Okanogan Rivers

Between 1967 and 2002, an average of 206 naturally produced steelhead spawned in the Methow River (range; 1-587; Table 3; Figure 7). In the Okanogan River, spawning escapement has ranged from 1 to 156, averaging 55 fish (Table 3; Figure 8). The 12-year geometric mean of spawners in the Methow River has ranged from 36 to 242, and is currently (2002) 202 (Table 3). For the Okanogan River, the 12-year geometric mean has ranged from 11 to 64 and is currently 53 (Table 3).

In the Methow and Okanogan rivers, the return per spawner has averaged 1.82 (range; 0.08-8.65) if hatchery fish do not produce any returning spawners, and averages 0.19 (range; 0.01-1.20) if hatchery fish produce the equivalent number of returning spawners as naturally produced fish (Table 3; Figure 9). The 12-year geometric mean of the return per spawner has averaged 1.32 (range 0.82-2.28) if hatchery fish are equivalents to naturally produced fish, or 0.12 (0.07-0.16) if they do not contribute (Table 3; Figure 10).

It is important to note for all stocks when examining the return per spawner ratios and making assumptions on the effectiveness of hatchery produced spawners that we do not mean to imply that their effectiveness is either zero or 100%. The "truth" is somewhere in between. Studies being conducted currently for spring Chinook in the Wenatchee River and in the future for steelhead in one or more rivers will give researchers better information to assess the naturally produced steelhead populations in the Upper Columbia Region.

Table 1 Naturally produced radio-tagged steelhead distribution prior to kelting upstream of Rock Island Dam, 1999-2000 and 2001-2002 (from English et al. 2001, 2003)

Location	2001-2002		1999-2000		Total Number	Average Percent
	Number	Percent	Number	Percent		
Wenatchee River	17	65.4	38	79.2	55	74.3
Entiat River	3	11.5	4	8.3	7	9.5
Mainstem Columbia (between RI and Wells)	6	23.1	4	8.3	10	13.5
Wells Hatchery (non-broodstock)	0	0.0	2	4.2	2	2.7
Total	**26**		**48**		**74**	
Methow River	16	72.7	18	75.0	34	73.9
Okanogan River	4	18.2	5	20.8	9	19.6
Mainstem Columbia (upstream of Wells)	2	100.0	1	100.0	3	
Total	**22**		**24**		**46**	

Table 2 Summary statistics for determining naturally produced (NP) steelhead escapement and run reconstruction for the Wenatchee and Entiat Rivers

	Stlhd. Passed	% NP	NP Escapement		NP escpmt.		GEO-M NP escpmt.		Returns		Return per spawner for Wenatchee and Entiat			
				> harvest & presp.									GEO-M	GEO-M
	(RI-WLS)	Wen., Ent.	<hrvst.	mortality	Wen.	Ent.	Wen.	Ent.	Wen.	Ent.	H. eff. = 0	effect. = 1	H. eff. = 0	H. eff. = 1
1967	4,032	0.80	3226	1771	1316	168			257	33	0.20	0.14		
1968	5,768	0.70	4038	2527	1878	240			244	31	0.13	0.08		
1969	3,588	0.50	1794	1155	858	110			173	22	0.20	0.09		
1970	1,547	0.35	541	185	138	18			137	18	0.99	0.31		
1971	4,530	0.20	906	507	377	48			110	14	0.29	0.05		
1972	2,919	0.15	438	202	150	19			191	24	1.27	0.17		
1973	3,337	0.15	501	295	219	28			300	38	1.37	0.18		
1974	1,305	0.15	196	110	82	10			284	36	3.46	0.47		
1975	2,208	0.15	331	130	97	12			229	29	2.37	0.32		
1976	3,156	0.23	725	248	184	24			249	32	1.35	0.28		
1977	4,644	0.22	1043	605	450	58			249	32	0.55	0.11		
1978	1,727	0.19	335	197	146	19	290	37	276	35	1.88	0.33	0.75	0.18
1979	3,729	0.21	776	410	305	39	256	33	459	59	1.51	0.28	0.88	0.19
1980	3,574	0.20	714	237	176	22	210	27	774	99	4.40	0.79	1.19	0.22
1981	3,463	0.22	763	478	355	45	196	25	1034	132	2.91	0.58	1.48	0.26
1982	1,895	0.25	475	94	70	9	185	24	1368	175			1.54	0.26
1983	10,141	0.14	1414	914	679	87	194	25	13 18	168	1.94	0.24	1.83	0.30

	Stlhd. Passed	% NP	NP Escapement		NP escpmt.		GEO-M NP escpmt.		Returns		Return per spawner for Wenatchee and Entiat			
				> harvest & presp.									GEO-M	GEO-M
	(RI-WLS)	Wen., Ent.	<hrvst.	mortality	Wen.	Ent.	Wen.	Ent.	Wen.	Ent.	H. eff. = 0	effect. = 1	H. eff. = 0	H. eff. = 1
1984	8,464	0.17	1463	919	683	87	220	28	1883	241	2.76	0.43	1.96	0.32
1985	12,132	0.21	2515	1859	1382	177	257	33	1406	180	1.02	0.19	1.91	0.32
1986	9,582	0.21	1967	1770	1315	168	323	41	1011	129	0.77	0.20	1.66	0.30
1987	7,239	0.41	2980	2682	1993	255	416	53	723	92	0.36	0.16	1.40	0.28
1988	4,840	0.33	1588	1430	1062	136	482	62	1125	144	1.06	0.36	1.37	0.29
1989	4,751	0.53	2507	2256	1676	214	538	69	536	69	0.32	0.18	1.31	0.30
1990	3,131	0.28	888	800	594	76	604	77	524	67	0.88	0.26	1.22	0.29
1991	3,176	0.49	1550	1395	1036	133	669	86	432	55	0.42	0.26	1.08	0.29
1992	5,451	0.23	1241	1117	830	106	761	97	485	62	0.58	0.15	0.90	0.25
1993	2,335	0.32	759	683	507	65	784	100	437	56	0.86	0.28	0.81	0.23
1994	3,457	0.20	704	634	471	60	919	118	301	39	0.64	0.13	0.79	0.22
1995	3,233	0.31	1006	906	673	86	919	117	369	47	0.55	0.18	0.71	0.22
1996	3,177	0.19	588	529	393	50	877	112	1111	142	2.82	0.56	0.71	0.22
1997	3,619	0.17	614	552	410	52	793	101	1941	248	4.73	0.74	0.81	0.25
1998	1,979	0.21	408	367	273	35	696	89						
1999	2,765	0.24	663	597	443	57	614	78						
2000	4,236	0.42	1789	1610	1196	153	620	79						
2001	10,084	0.42	4284	3855	2864	366	648	83						
2002	5,817	0.33	1931	1738	1291	165	691	88						

	Stlhd. Passed	% NP	NP Escapement		NP escpmt.		GEO-M NP escpmt.		Returns		Return per spawner for Wenatchee and Entiat			
				> harvest & presp.									GEO-M	GEO-M
	(RI-WLS)	Wen., Ent.	<hrvst.	mortality	Wen.	Ent.	Wen.	Ent.	Wen.	Ent.	H. eff. = 0	effect. = 1	H. eff. = 0	H. eff. = 1
2003	17,481	0.28	2375	2137	1588	203	716	92						
Avg.:	**4,825**	**0.29**	**1,352**	**1,024**	**761**	**97**	**534**	**68**	**643**	**82**	**1.42**	**0.28**	**1.22**	**0.26**
Min.:	**1,305**	**0.14**	**196**	**94**	**70**	**9**	**185**	**24**	**110**	**14**	**0.13**	**0.05**	**0.71**	**0.18**
Max.:	**17,481**	**0.80**	**4,284**	**3,855**	**2,864**	**366**	**919**	**118**	**1,941**	**248**	**4.73**	**0.79**	**1.96**	**0.32**

RI-WLS Rock Island dam to Wells Dam; Wen = Wenatchee, Ent = Entiat; Stlhd = Steelhead; hrvst = harvest; escpmt = escapement; Geo-M = Geometric mean; H. eff = Hatchery Effective

Table 3 Summary statistics for determining naturally produced (NP) steelhead escapement and run reconstruction for the Methow and Okanogan Rivers

	Stlhd. passed	% NP	NP escapement		NP escpmt.		GEO-M NP escpmt.		Returns		Return per spawner for Methow and Okanogan			
				> harvest & presp.									GEO-M	
Year	> Wells	Met., Okn.		mortality	Met.	Okn.	Met.	Okn.	Met.	Okn.	H. eff. = 0	H. eff. = 1	H. eff. = 0	H. eff. = 1
1967	1,474	0.70	1032	183	135	36			161	43	1.19	0.75		
1968	2,112	0.70	1478	765	565	150			124	33	0.22	0.14		
1969	1,391	0.50	696	363	268	71			30	8	0.11	0.05		
1970	1,597	0.35	559	93	69	18			17	5	0.24	0.08		
1971	3,782	0.20	756	376	278	74			21	6	0.08	0.01		
1972	1,894	0.10	189	48	35	9			68	18	1.92	0.17		
1973	1,820	0.05	91	37	27	7			112	30	4.12	0.19		
1974	580	0.05	29	15	11	3			84	22	7.49	0.34		
1975	517	0.15	78	1	1	1			57	15				
1976	4,664	0.10	466	128	95	25			66	17	0.70	0.06		
1977	5,282	0.10	528	217	161	43			99	26	0.62	0.06		
1978	1,621	0.10	162	24	17	5	57	17	151	40	8.65	0.78	0.82	0.13
1979	3,695	0.10	370	137	101	27	55	16	128	34	1.26	0.11	0.83	0.11
1980	3,443	0.10	344	13	9	2	39	12	124	33		1.20	0.95	0.13
1981	4,096	0.10	410	194	143	38	37	11	185	49	1.29	0.12	1.21	0.14
1982	7,984	0.06	519	252	186	49	41	12	264	70	1.42	0.08	1.44	0.14
1983	19,525	0.01	252	105	77	21	36	11	290	77	3.75	0.04	2.13	0.16
1984	16,632	0.03	416	170	125	33	41	12	474	126	3.78	0.09	2.28	0.15

Year	Stlhd. passed > Wells	% NP Met., Okn.	NP escapement	> harvest & presp. mortality	NP escpmt. Met.	NP escpmt. Okn.	GEO-M NP escpmt. Met.	GEO-M NP escpmt. Okn.	Returns Met.	Returns Okn.	Return per spawner for Methow and Okanogan H. eff. = 0	Return per spawner for Methow and Okanogan H. eff. = 1	GEO-M H. eff. = 0	GEO-M H. eff. = 1
1985	19,867	0.04	838	324	239	64	49	14	392	104	1.64	0.06	2.08	0.14
1986	13,303	0.03	394	355	262	70	63	19	364	97	1.39	0.08	1.75	0.12
1987	5,493	0.12	681	613	453	120	105	28	340	90	0.75	0.13	1.62	0.12
1988	4,401	0.11	475	428	316	84	116	31	455	121	1.44	0.24	1.73	0.13
1989	4,600	0.13	603	542	401	106	126	33	147	39	0.37	0.08	1.65	0.14
1990	3,815	0.12	473	426	315	83	160	42	99	26	0.31	0.06	1.22	0.11
1991	7,751	0.11	829	746	552	146	184	49	68	18	0.12	0.02	0.99	0.10
1992	7,027	0.05	379	342	252	67	242	64	91	24	0.36	0.04	0.91	0.07
1993	2,494	0.08	195	175	130	34	240	64	130	35	1.01	0.10	0.89	0.07
1994	2,163	0.06	135	121	90	24	226	60	116	31	1.29	0.07	0.89	0.07
1995	942	0.12	116	104	77	20	226	60	213	56	2.76	0.31	0.86	0.08
1996	4,128	0.05	211	189	140	37	228	60	374	99	2.67	0.14	0.84	0.09
1997	4,107	0.02	99	89	66	17	205	54						
1998	2,984	0.08	227	204	151	40	195	52						
1999	3,504	0.14	490	441	326	86	190	50						
2000	6,280	0.08	474	427	316	84	190	50						
2001	18,528	0.05	883	794	587	156	196	52						
2002	9,478	0.07	653	588	434	115	202	53						
2003														

Appendix C: Steelhead Reconstructions

Year	Stlhd. passed > Wells	% NP Met., Okn.	NP escapement	> harvest & presp. mortality	NP escpmt. Met.	NP escpmt. Okn.	GEO-M NP escpmt. Met.	GEO-M NP escpmt. Okn.	Returns Met.	Returns Okn.	Return per spawner for Methow and Okanogan		GEO-M	
											H. eff. = 0	H. eff. = 1	H. eff. = 0	H. eff. = 1
Avg.:	**5,638**	**0.14**	**459**	**279**	**206**	**55**	**138**	**37**	**175**	**46**	**1.82**	**0.19**	**1.32**	**0.12**
Min.:	**517**	**0.01**	**29**	**1**	**1**	**1**	**36**	**11**	**17**	**5**	**0.08**	**0.01**	**0.82**	**0.07**
Max.:	**19,867**	**0.70**	**1,478**	**794**	**587**	**156**	**242**	**64**	**474**	**126**	**8.65**	**1.20**	**2.28**	**0.16**

Wen = Wenatchee, Ent = Entiat; Stlhd = Steelhead; hrvst = harvest; escpmt = escapement; Geo-M = Geometric mean; H. eff = Hatchery Effective

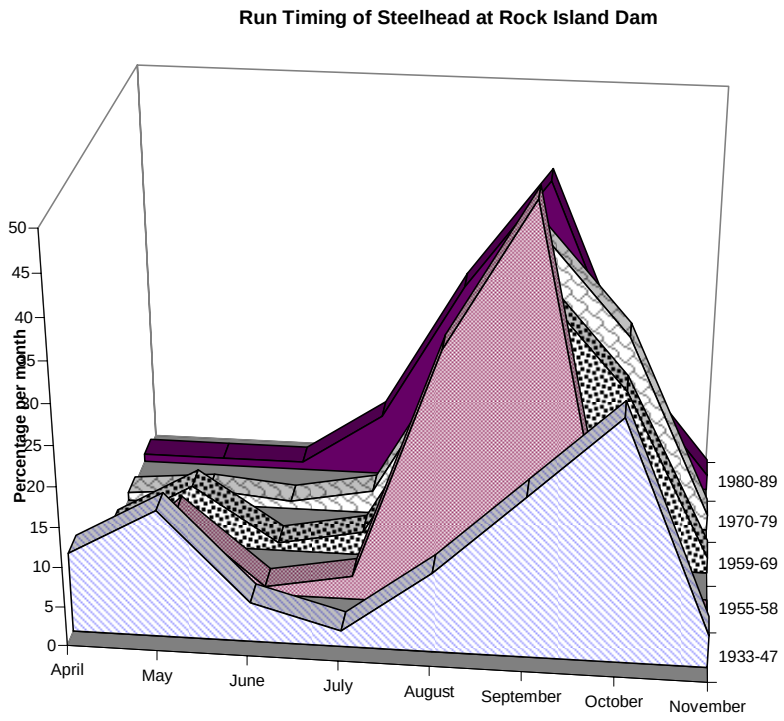

Figure 1 Percent passage of steelhead at Rock Island Dam between 1933-1989 (from Peven 1992; Chapman et al. 1994)

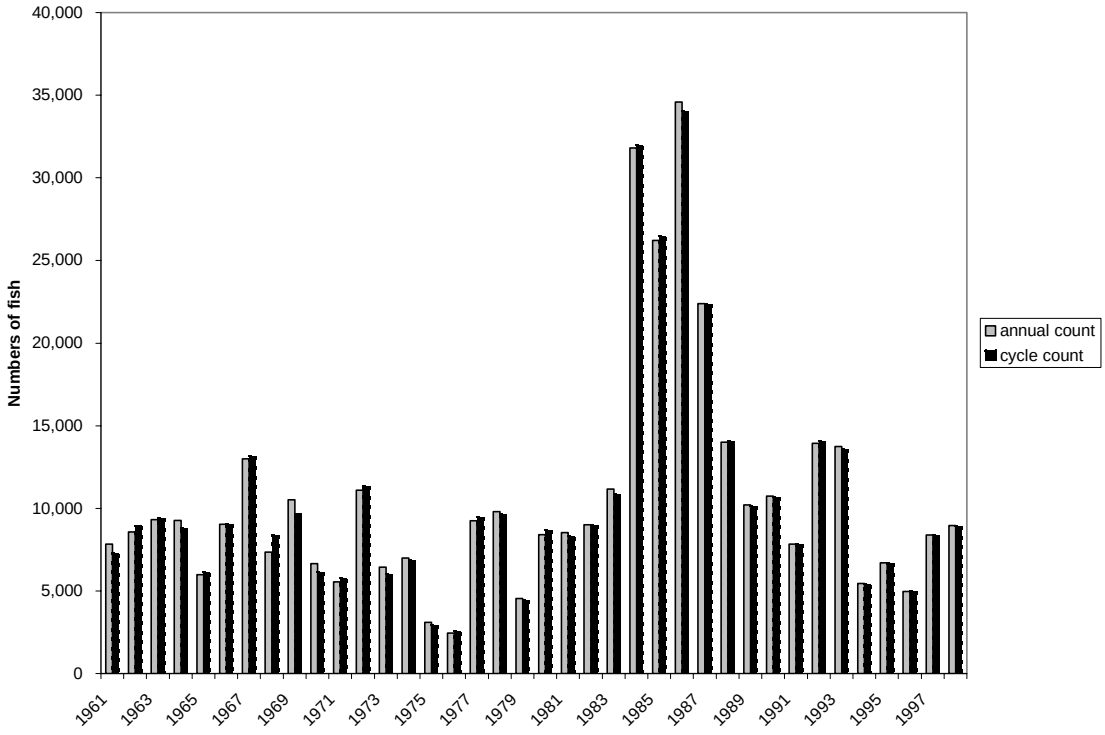

Figure 2 Comparison of cycle and calendar year counts for steelhead passing Priest Rapids Dam

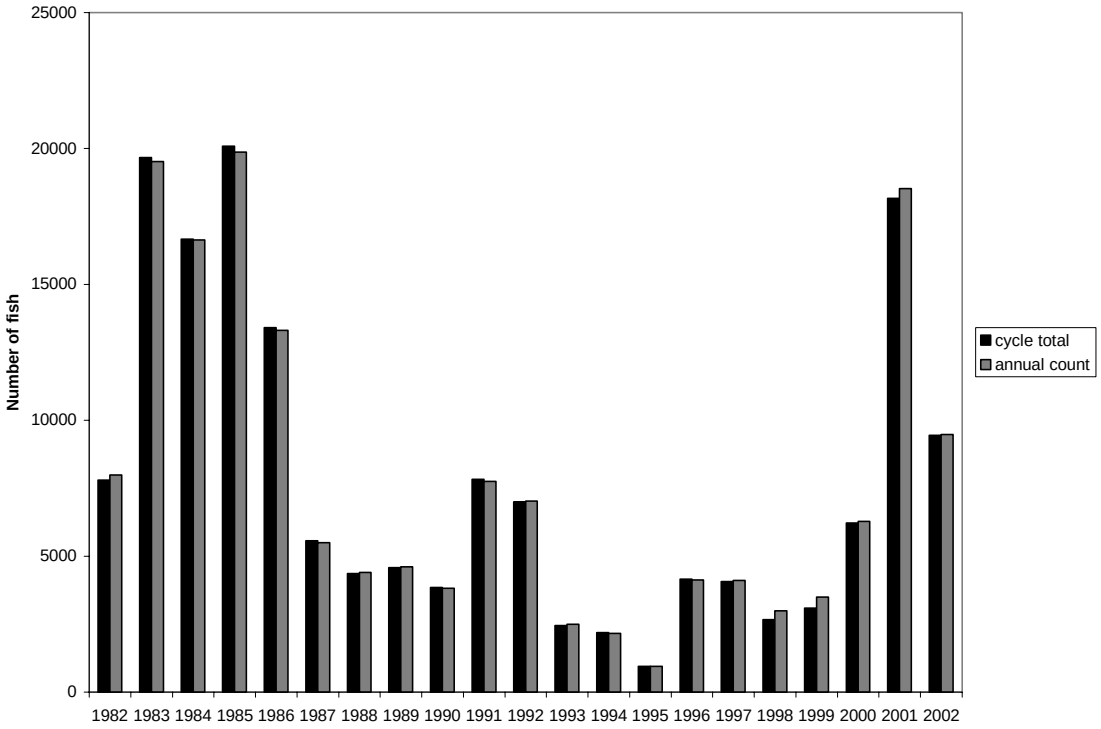

Figure 3 Comparison of cycle and calendar year counts for steelhead passing Wells Dam

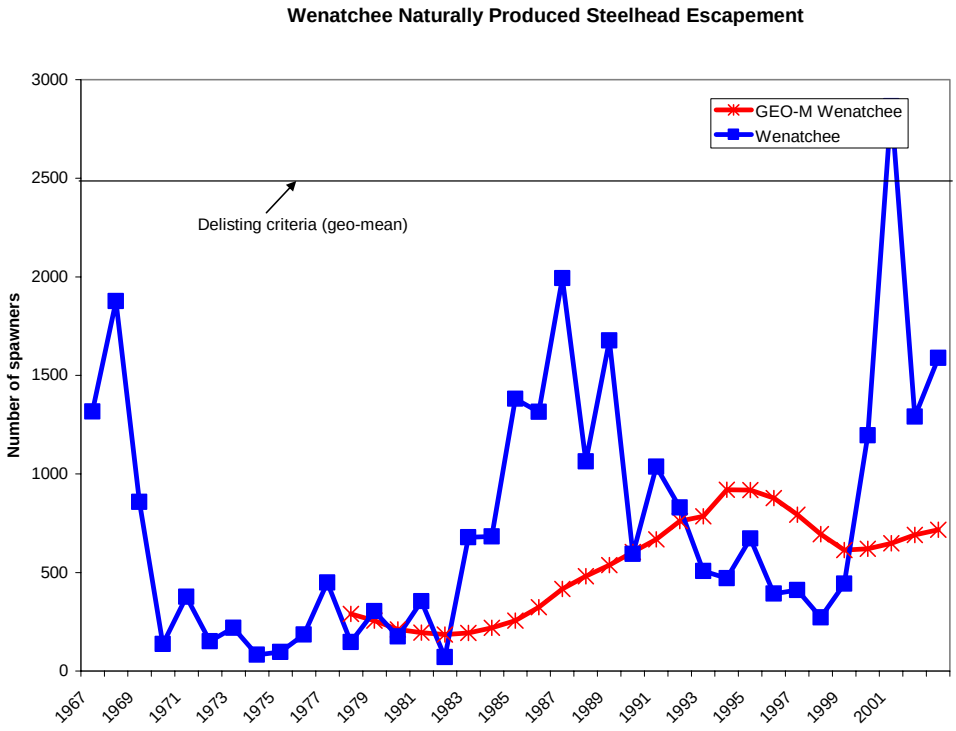

Figure 4 Naturally produced escapement of steelhead in the Wenatchee River

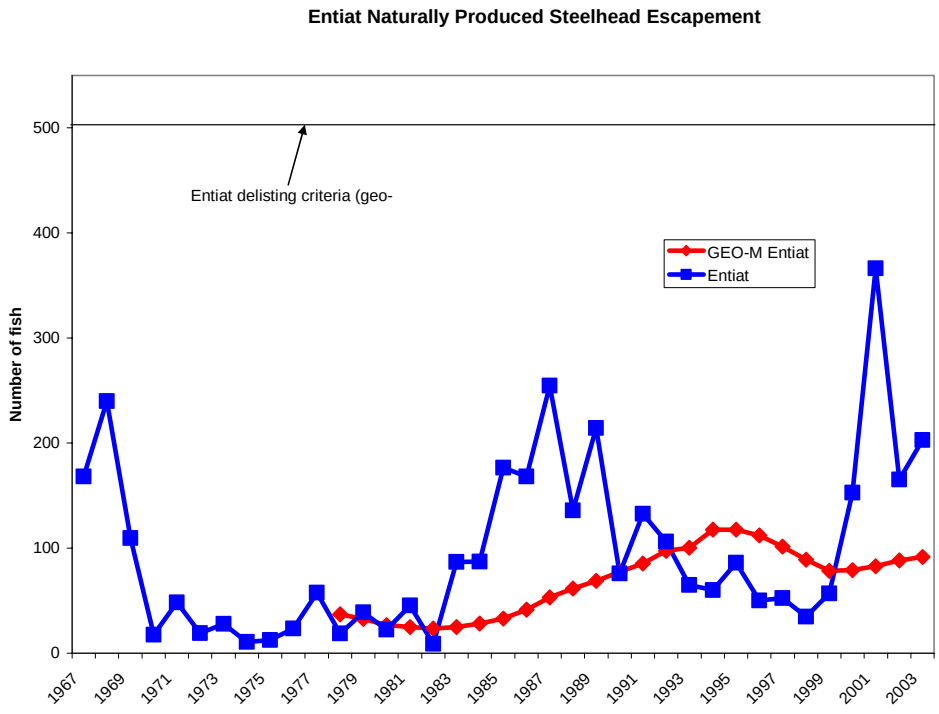

Figure 5 Naturally produced escapement of steelhead in the Entiat River

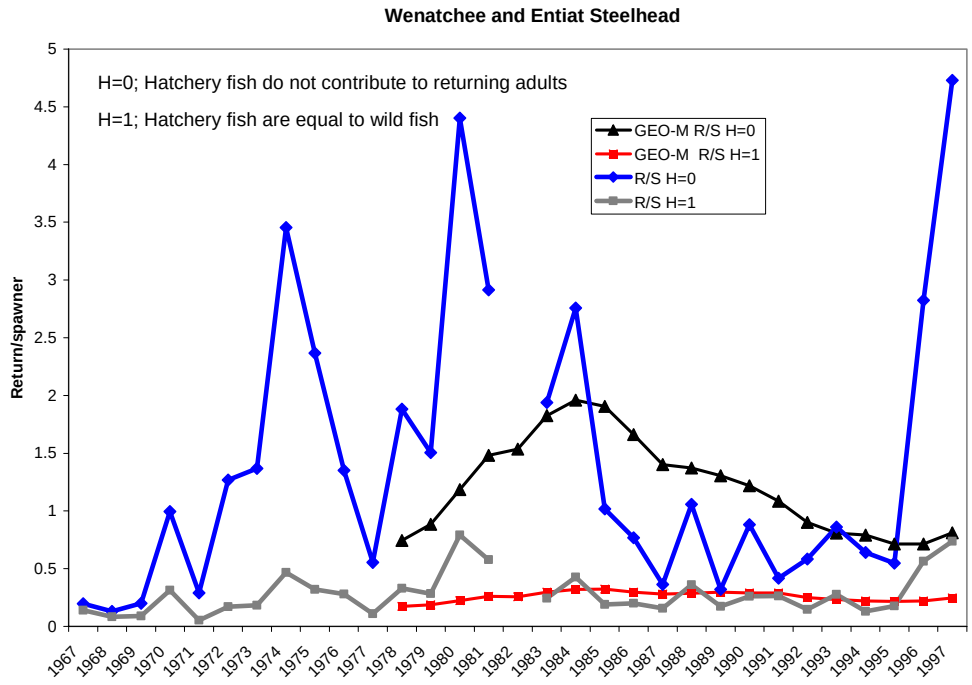

Figure 6 The return per spawner of naturally produced steelhead in the Wenatchee and Entiat Rivers. Two estimates of hatchery spawner reproductive success are shown; one if they are as effective and the second if they do not produce any returning adults to the spawning escapement

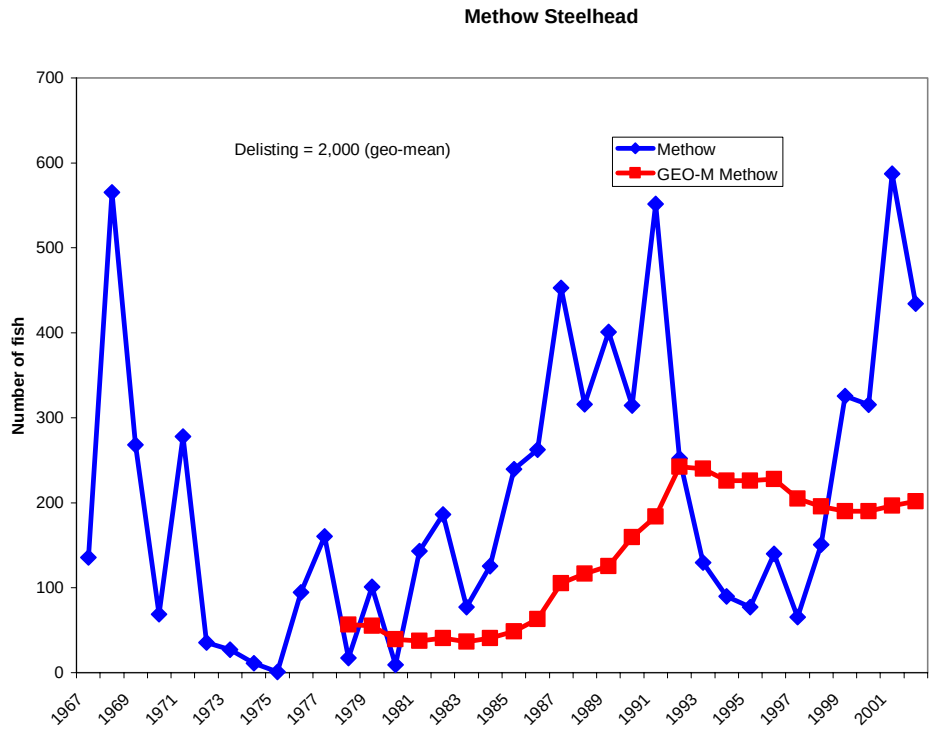

Figure 7 Naturally produced escapement of steelhead in the Methow River

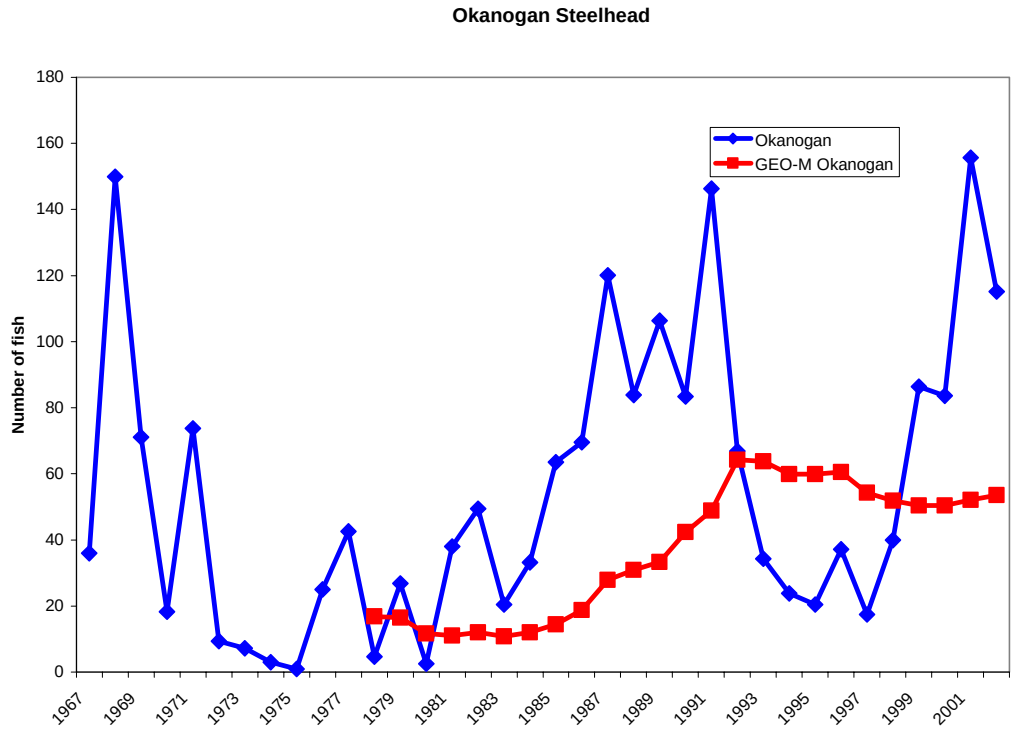

Figure 8 Naturally produced escapement of steelhead in the Okanogan River

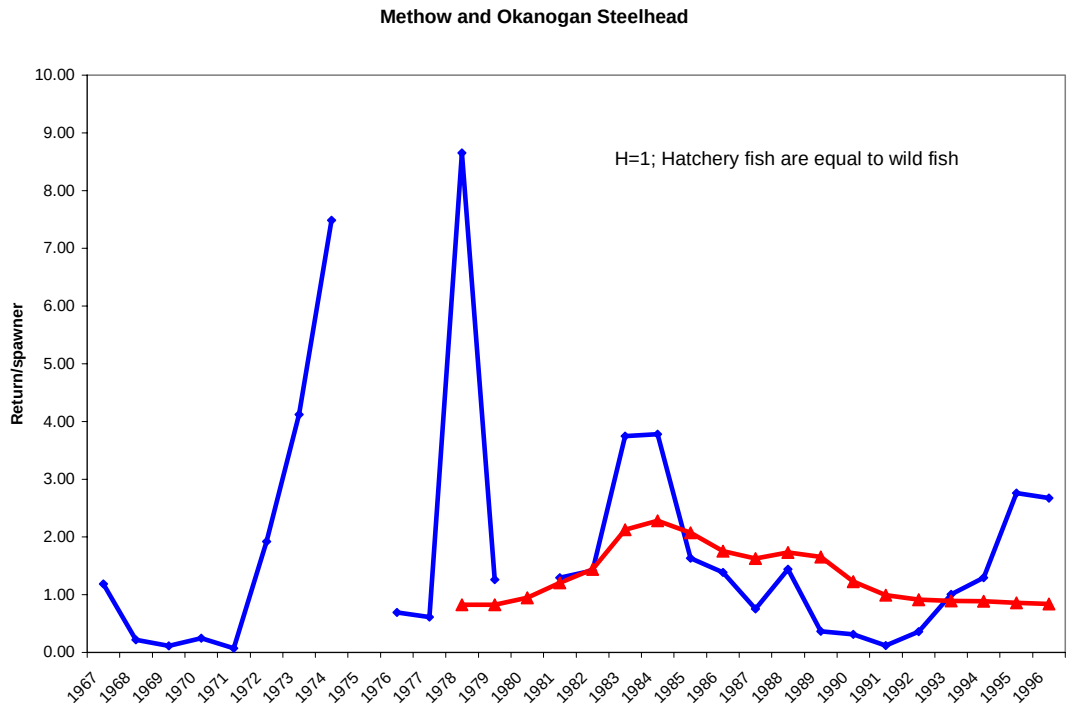

Figure 9 The return per spawner of naturally produced steelhead in the Methow and Okanogan Rivers. Hatchery spawner reproductive success is equivalent to naturally produced spawners

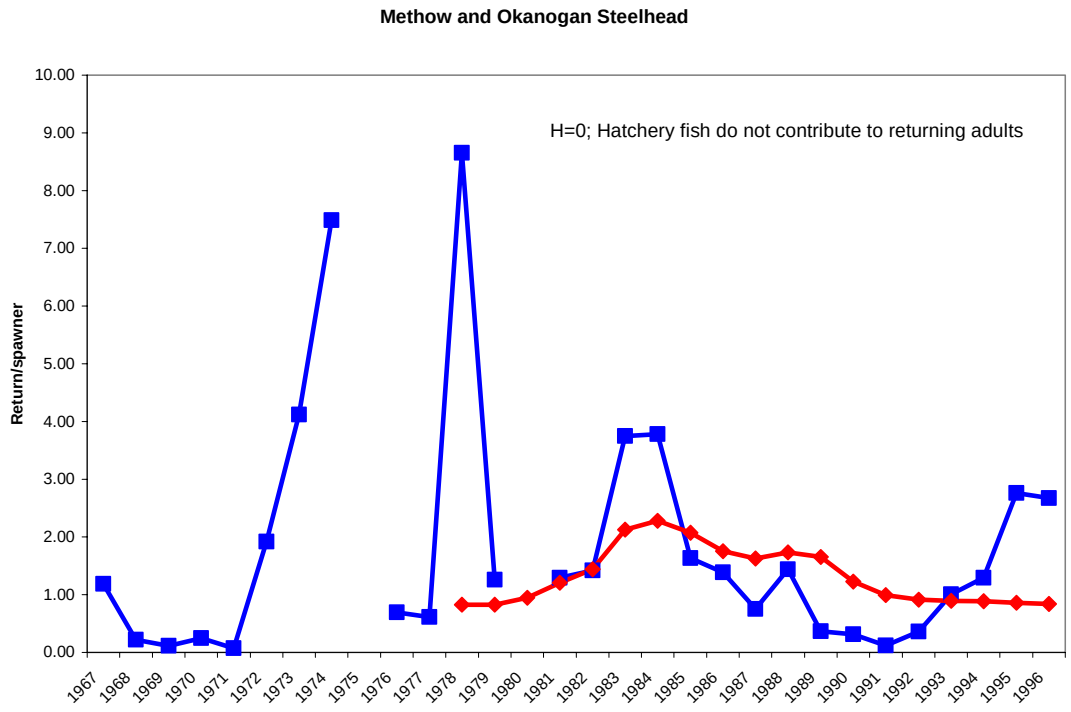

Figure 10 The return per spawner of naturally produced steelhead in the Methow and Okanogan Rivers. Hatchery spawners do not contribute to returning spawners