A Cursory Review of Hatchery Steelhead Returns to the Thompson River Watershed

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1. Introduction

In the late 1970's and 1980's, the stocking of hatchery steelhead in many BC streams was initiated jointly by federal and provincial fisheries agencies *in response* to federal salmon management plans intended to enhance Pacific Salmon with hatchery production. The stocking of steelhead was seen as a means of mitigation for expected increases in steelhead interception rates (for some stocks) in enhanced commercial salmon fisheries as well as increases in juvenile competition that was expected to result from the stocking of salmon in steelhead bearing streams (A. Tautz, pers. comm.). Such was the case in the Thompson watershed where hatchery steelhead fry and parr were stocked from 1979 to 1995.

From about the time that the first Thompson hatchery steelhead were returning as adults in the mid 1980's, the abundance of Thompson steelhead has undergone a large decline of about 60%. Trends of this magnitude or more have also been observed in steelhead and some salmon stocks throughout southern BC and the northwest states and have been associated with a survival regime shift associated mostly with a cyclical change in climate and the ocean environment (Welch et al. 2000, Smith and Ward 2000, Hare et al. 1999). The number of hatchery steelhead that returned failed to meet expectation of managers and hatchery operations were discontinued with the last stocking of unmarked fry in 1995 (I. McGregor, pers. comm.).

Despite the decline in steelhead survival and abundance, sport fishing for steelhead on the Thompson has continued over this time period with the aid of regulatory measures that reduced fishing mortality. However in 2008 and after three steelhead generations of low survival conditions, the Thompson steelhead sport fishery remained closed for the first time as a result of an inseason forecast indicating that abundance was unlikely to exceed conservation limits. This latest management action has prompted a call by some for a re-initiation of steelhead hatchery stocking. This review is intended to provide information and a cursory analysis of the stocking program that occurred from 1979 to 1995.

2. Stocking History and the Degree of Fry and Parr Population Augmentation

Stocking began in 1979 with the stocking of fry and by 1981 parr were being stocked along with fry (Table 1). In the early 1980's, stocking of marked and unmarked *parr* ranged from 40,000 to 50,000. The majority of these were marked with adipose fin clips. In the mid-1980's, stocking of marked and unmarked *fry* often exceeded 300,000, peaking in 1986 at 478,500 (Table 1). Unlike parr, the proportion of released fry that were marked in any given year varied from 0-60%.

Recent studies of parr recruitment suggest that age 1+ parr abundance in the steelhead bearing waters of the Thompson watershed is in the order of 200,000 when corresponding escapements are in the order of 1000-2000 spawners (Decker *et al.* 2009). The apparent stability of the parr population over this range of preceding spawners suggests that such levels of parr abundance may be near maximum. Steelhead escapement records date back to 1984 and over this time period escapements were sufficient large to achieve such levels of parr abundance. Were escapements in the early 1980's also sufficiently large to produce parr numbers in the order of 200,000? Steelhead sport catch and effort estimates suggest that escapements in those years were indeed sufficiently large. This suggests that the stocking of 40,000 to 50,000 hatchery parr per year in the early 1980's may have increased the parr population (at the time of stocking) by a magnitude of about 20% or 25%.

In the mid-1980's, wild fry abundance is expected to have been in the order of 1.75 million, based on escapement records and assuming 2:1 female to male spawner sex ratios (Morris 2002, Bennett 1998) and 10% egg to fry survival (Moore and Olmsted 1985). This suggests that the stocking of about 300,000 (plus) hatchery fry increased the fry population (at the time of stocking) by a magnitude of about 20%.

3. Stocking in Comparison to Adult Abundance Trends

When compared to adult abundance trends, there is no clear indication that steelhead numbers improved as a result of stocking (Figure 1). On the contrary, stocking coincided with a decline in abundance. However the effect of fry and parr population augmentation in the order of 20% could have been obscured in the adult trend data by confounding environmental, ecological, or exploitation factors, and perhaps exacerbated by measurement errors and inconsistencies in the estimation of adult abundance trend data. We know that the returns of the mid 1980's, at the start of the adult abundance time series, were reflective of a period of exceptionally high survival observed throughout much of the steelhead range in southern BC, Washington and Oregon which by about 1990 was followed by a sudden downward shift (Ahrens 2004, Smith and Ward 2000, Welch et al. 2000). For Thompson steelhead, the shift to a lower survival regime is apparent in the adult recruitment data. The apparent trend in pre-fishery abundance in Figure 1 is largely due to this survival shift, the mechanism of which remains unknown.

4. Return Rate of Marked Hatchery Parr and Fry

To estimate the overall magnitude of the adult return rate of marked hatchery fry and parr, a simple estimation model was used that predicts the number of marked adult returns to the sport fishery based on the number of marked fry and parr that were stocked as follows:

4.1. Method

Beginning with the time series of marked fry and parr stockings (Table 1), the time delay between stocking and adult returns was based on the age composition of wild adult Thompson steelhead. The dominant age class of adult Thompson steelhead is total age 5 (returning from sea in their 4th year and approaching 5 years of age at time of spawning). Based on scale analyses (R. Bison data on file; McGregor 1986), a constant age structure was assumed comprised of 80% 5-year-olds and 20% six-year-olds. The predicted adult returns of marked parr were then computed as:

$$adults_{parr,t} = s_{parr}\left[0.8 * parr_{t-4} + 0.2 * parr_{t-5}\right]$$

where t denotes the spawning year and s_{parr} is the parr to adult survival rate.

Similarly, predicted adult returns from marked fry were computed as:

$$adults_{fry,t} = s_{fry}\left[0.8 * fry_{t-5} + 0.2 * fry_{t-6}\right]$$

where s_{fry} is the fry to adult survival rate.

The total number of predicted returns of marked adults, prior to being captured in interception fisheries, is simply the sum of:

$$adults_t = adults_{parr,t} + adults_{fry,t}$$

In order to account for losses in interception fisheries, the predicted number of hatchery steelhead to reach the sport fishery in a given year was computed according to the estimated fishing mortality rates in the interception fisheries (u_t) as follows:

$$N_t = adults_t(1 - u_t)$$

The sport fishery catch tends to equate to abundance (Morris and Bison 2004; MOE file data 2001). Therefore, predictions of catch of marked hatchery steelhead in the sport fishery were simply equal to the number of steelhead present:

$$C_t = N_t$$

The data are the observed catch of marked hatchery steelhead (x_t). The unknown parameters to be estimated are the parr-to-adult and fry-to-adult survival rates (s_{fry} and $s_{parr)}$. These were estimated by minimizing least square deviations between the predicted catch (C_t) and observed catch (x_t) of marked adults.

4.2. Data

Records of catch of marked steelhead are available from the BC Ministry of Environment Steelhead Harvest Questionnaire Survey, however these catch estimates are known to be biased high relative to catch estimates derived from inseason surveys (DeGisi 1999). For the Thompson, Morris and Bison (2004) showed that catch estimates from inseason angler surveys tend to equate to steelhead abundance. So to use the Steelhead Harvest Questionnaire catch data as a measure true abundance of marked hatchery steelhead in the sport fishery, the coefficients developed by DeGisi were used to correct for the positive reporting bias. The mean upward discrepancy for Steelhead Harvest Questionnaire estimates were 83% for retained catch and 109% for released catch (DeGisi 1999).

The time series of exploitation rate indices are available from Bison (2007). These date back to 1992 and were considered to be estimates of true exploitation rate for this simple and crude estimation procedure (Table 2). Given that stocking started in 1979 with the stocking of fry, the first returns of hatchery adult steelhead were expected in the spawning year 1984. To account for exploitation prior to 1992 and back to 1984, exploitation rate estimates were based on the assumption that bycatch exploitation was equal to the highest observed for the period from 1992 onward (a value of 0.43/year) based on a historical description of the intensity of fishing as reported in Anonymous (1998). The additional exploitation by the sport fishery was based on the annual number of steelhead mortalities from the Steelhead Questionnaire Survey. This was computed by summing the number of steelhead kept with the number of steelhead released, the later multiplied by a per capture mortality rate of 0.05 (Anonymous 1998). The annual numbers of steelhead kept and released were corrected for reporting bias according to DeGisi (1999) using the coefficients described above. So given estimates of escapement (N''), sport mortalities (M) and exploitation in bycatch fisheries ($u_{bycatch}$), the prefishery steelhead abundance (N'), sport exploitation rate (u_{sport}), and total exploitation rate (u_{total}) were computed as:

$$N' = \frac{(N'' + M)}{(1 - u_{bycatch})}$$

$$u_{sport} = \frac{M}{N'}$$

$$u_{total} = u_{bycatch} + u_{sport}\,.$$

4.3. Results

Assuming the fixed and constant spawning age structure of 80% five-year-olds and 20% six-year-olds, the results suggest that the estimated survival rate from hatchery parr to adult was in the order of 0.3% and that the survival rate from hatchery fry to adult was in the order of 0.1%. These survival rates are reflective of the period from 1983 to 1998 when most of the hatchery fish returned. By comparison, parr to adult survival rates of wild parr have been estimated to be 0.7% (range 0.3% to 1.4%); about 2 times higher on average (2000-2004 brood years, Decker *et al.* 2009).

To examine the assumption about the exploitation rate in bycatch fisheries prior to 1992, s_{fry} and s_{parr} were re-estimated by minimizing least square deviations between the predicted catch (C_t) and observed catch (x_t) of marked adults for only the period from 1992 onward, thus omitting any assumptions about exploitation in bycatch fisheries prior to 1992. Fitting the model to this shortened catch time series resulted in no change to the fry-to-adult survival rate estimate of 0.1%. However the parr-to-adult survival rate could not be estimated because adult returns from parr stocking occurred prior to 1992.

Much of the variation in the observed catches is not explained by the model, however this is to be expected given the assumption of constant survival and constant and fixed age structure (Figure 2). It seems more likely that the unexplained variation is the result of variation in annual survival rather than alternative hypotheses and assumptions about the age structure. To explore this further, if the assumption about age structure is altered and we allow it to consist of four age classes instead of two (four-year-olds to seven-year-olds), and if we treat these as 4 additional free parameters, the model explains the variation in the observed catches better as would be expected (Figure 3). However, the estimated parr to adult and fry to adult survival rates, when rounded off to one significant figure, are the same as those estimated under the assumption of constant and fixed age structure of 80% five-year-olds and 20% six-year-olds. Uncertainty about age structure is therefore not important if we are concerned with simply estimating the overall survival rate of stocked steelhead parr and fry to one significant figure.

5. Expected Adult Returns of Hatchery Steelhead in Comparison to Adult Abundance Trends

If we take the survival rates estimates for marked hatchery parr and fry and compute the total expected return of both marked and unmarked hatchery adults from records of marked and unmarked fry and parr stockings, the total prefishery returns would be expected to be in the order of low to mid hundreds (Table 3, Figure 4).

The abundance time series for Thompson steelhead begins in 1984. The mid 1980's were years of relatively high abundance both pre-fishery and on the spawning grounds. However, by the late 1980's the survival regime shift had taken place. Given that almost all wild Thompson steelhead return as either 5 or 6 year olds, the relationship between spawners and adult recruits over this time period (and to date) represents a low survival regime period (Figure 5). If we compute the average recruitment relationship over this time period in the form of a Ricker stock recruitment relationship, by regression of ln(R/S) on S:

$$ln(R/S_t) = a - bS_t + w_t$$

and by minimizing the sum of squared residuals w_t, we find there is a positive correlation between the recruitment anomalies (w_t) and the expected number of returning hatchery steelhead for the corresponding years (Figure 5). Interestingly, the anomalies tend to equate to the expected number of adult returns from stocking. This correlation may be indicative of an overall increase in steelhead abundance due to stocking, however autocorrelation in such recruitment time series is common in fishes (Pyper and Peterman 1998) and it is possible that the period of stocking coincided with a period of positive recruitment anomalies due to other factors.

If we repeat the above analyses for the Chilcotin stock and compare, we find evidence that the trend in recruitment anomalies in the Thompson is not unique. The stocking history for the Chilcotin is much shorter and less intense than that which occurred in the Thompson and this provides some contrast between stocking scenarios. Despite the difference in duration and intensity of stocking, the recruitment anomalies for Chilcotin and Thompson trend similarly suggesting that factors other than stocking are the cause of the declining trends at least for the most part (Figure 6). Among the many other hypothetical causes, those associated with the marine life history phase are most compelling. Plotting the Chilcotin recruitment anomalies further back to the start of the Chicotin steelhead abundance time series illustrates the magnitude of effect of marine survival changes on interior steelhead abundance and helps to put any potential effect due to stocking into some perspective (Figure 8). Not unrelated, there is also evidence that a life history shift between steelhead and rainbow trout may be occurring. Recent availability of rainbow trout escapement data from the Deadman River shows that since 1999, rainbow trout escapements have trended upward while steelhead escapements have trended downward (McCubbing and Bison 2009, McCubbing 2009). Over this same time period, parr populations have remained relatively stable (Decker *et al.* 2009).

To answer such a question as to whether hatchery stocking of Thompson steelhead results in an increase in overall abundance would require repetitive periods of experimental stocking and non-stocking so as to break up the confounding potential competition and predation effects (between stocked and wild steelhead and rainbow trout) with the shared environmental effects (Walters and Martell 2004). The monitoring of steelhead abundance and exploitation rate would need to continue as would surveys of hatchery returns in the sport catch. Marking of hatchery juveniles would be necessary and the additional marking of wild juveniles would help provide insight into the effects of stocking on the wild stock. Monitoring the abundance and the mark rates on the sympatric rainbow stock(s) would provide insight into residualism rates of both wild and hatchery juveniles as well as longer term trends about the population dynamics of the two life history forms which we know are reproductively linked. There is also the option of directly sampling rates of anadromy and residualism using otolith microchemistry techniques (Zimmerman and Reeves 2000).

6. The Stocking Option Under Current Policy

The current BC government policy on the hatchery stocking of steelhead (Steelhead Stream Classification Policy and Procedure, Effective December 13, 2005) states that the objective is to maintain healthy, self-sustaining wild steelhead populations in British Columbia. One of the purposes of the policy is to recognize the risks of hatchery augmentation and to acknowledge the lack of scientific evidence to support the use of traditional hatchery practices to recover “at-risk” steelhead stocks.

The criteria for classifying a stream as "hatchery-augmented" by which stocking could proceed include:

1. Systems which have been historically augmented and where continued augmentation is not considered to pose a risk to extant wild stocks or;
2. Systems where a wild stock has been depleted or otherwise impacted to the point that recovery is not considered possible or;
3. Systems where a steelhead population never existed and potential impacts to other native species have been evaluated and are considered acceptable.

Criteria 3 does not apply in the case of the Thompson.

In regard to criteria 2, the recent adult recruitment data for Thompson indicates that the stock has the potential to be self sustaining provided exploitation remains low enough, but it also indicates that the potential abundance is currently low (unfished equilibrium stock size ~ 2300) relative to the more abundant period prior to the late 1980's (Figure 4). Simulation tests suggest that a low return (<850) as was forecasted in 2008 should not come as a surprise under the current: survival regime, level of exploitation, and level of potential measurement error in both the estimation of abundance and exploitation rate. However, while it is standard practice to analyze past recruitment patterns as a guide for immediate and future management, the ongoing downward trend in steelhead recruitment anomalies may render such analyses to be uninformative and not applicable to current or future situations. Continued monitoring of Thompson steelhead recruitment and further development in the study and monitoring of Thompson rainbow trout would help answer this question in the soonest possible manner. It would also help our understanding of what level of recovery is possible for the anadromous form of the stock or whether the potential for recovery is once again changing as it did in the late 1980's.

In regard to criteria 1, the risk to extant wild steelhead stocks include:

1. Direct exploitation of the wild stock to produce hatchery fish
2. Juvenile competition between hatchery and wild fish
3. Risk of genetic changes

With a hatchery program, there would have to be direct added exploitation of wild fish by removing wild spawners to produce the hatchery juveniles. There may also be a potential for increased exploitation in the sport fishery due to hatchery steelhead harvesting opportunity causing an increase in effort relative to the stock size and therefore some increase in catch and release mortality rate on the wild stock. Combined with mortality in bycatch fisheries, a hatchery program would increase the overall exploitation rate on the wild stock at a time when recruitment is trending downward.

To manage the risk of genetic change leading to potential loss of long-term population fitness and viability (Araki et al. 2009), removal of hatchery fish prior to spawning to less than 5% of the spawning population has been recommended in similar cases in other jurisdictions (Anonymous 2008a, Anonymous 2008b). It is unlikely that the current community of anglers that frequent the Thompson would voluntarily kill a hatchery steelhead in the Thompson, but they would probably be soon replaced with others who would, changing the character of the fishery. Given that steelhead sport catch tends to equate to steelhead abundance, it is possible that the majority of hatchery steelhead could be removed with sufficient public awareness efforts. Whether or not 95% of the hatchery fish could be removed would have to be the focus of an enhanced monitoring program and would require the reintroduction of fish handling operations during spawner surveys, operations that the ministry has moved away from to not only lessen costs and improve data quality but to also lessen potential negative reproductive effects on the stock (McCubbing et al. 2001). But even so, it is unlikely that 95% of hatchery *residuals* could be removed by the trout and steelhead fisheries combined. Therefore managing the risk of genetic change to current standards is not likely possible.

Even if the vast majority of hatchery fish could be successfully removed prior to spawning, one would expect that hatchery stocking would increase the likelihood of sport fishery closures given the current management approach. The sport fishery is currently managed according to a spawner abundance forecast made inseason based on gillnet test fishing data (Albion test fishery). As it stands, a forecast of 850 spawners must be exceeded to permit the sport fishery to proceed. This abundance represents a limit reference point as described in Johnston et al. (2000). Since hatchery fish would be externally marked presumably with an adipose fin clip and therefore identifiable in the test fishery catches, a forecast of wild steelhead spawners based on the wild catch would still be possible. The test fishery catches of hatchery steelhead would therefore not be used in the spawner forecast if the sport fishery was managed for the removal of the vast majority of the hatchery fish prior to spawning. In theory, one would expect that the chances that the sport fishery would open would be lessened given the expected increase in juvenile competition between wild and hatchery juveniles. If survival is density dependent after stocking age, one would also expect the productivity of the wild stock to also be lessened by stocking, placing it at greater risk of overexploitation (most of which occurs as bycatch in salmon fisheries).

In summary, the reimplementation of hatchery practices would involve some unavoidable risks to the wild stock, the level of which is a function of the intensity of stocking combined with the intensity of the interactive and carryover effects between stocked and wild fish combined further with fishing effects. Past experience suggests that benefits in terms of increasing abundance are by no means guaranteed and in the long run may not prove to be benefits at all, but rather impairments to the longer term viability of the wild stock. It would seem therefore that any consideration for a reintroduction of hatchery stocking in the Thompson be regarded as experimental at best.

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Table 1. Hatchery steelhead releases into the Thompson watershed. AD denotes adipose clipped.

Brood Year	AD parr released	AD fry released	Unmarked parr released	Unmarked fry released	Eyed eggs released	Total parr released	Total fry released
1979		7300		10900		0	18200
1980	39248			37000		39248	37000
1981	26186		12400			38586	0
1982	51404			10000		51404	10000
1983	50919			82930		50919	82930
1984	41790			300000		41790	300000
1985	40790	172277		125645	98305	40790	297922
1986				478500		0	478500
1987				134692		0	134692
1988		181037		147485		0	328522
1989		157183		200595		0	357778
1990		154400		225285		0	379685
1991		218000		133830		0	351830
1992		102757		106423		0	209180
1993				157833		0	157833
1994				147644		0	147644
1995				183726		0	183726
1996						0	0
1997						0	0
1998						0	0
1999						0	0
2000						0	0
2001						0	0
2002						0	0
2003						0	0
2004						0	0
2005						0	0
2006						0	0
2007						0	0

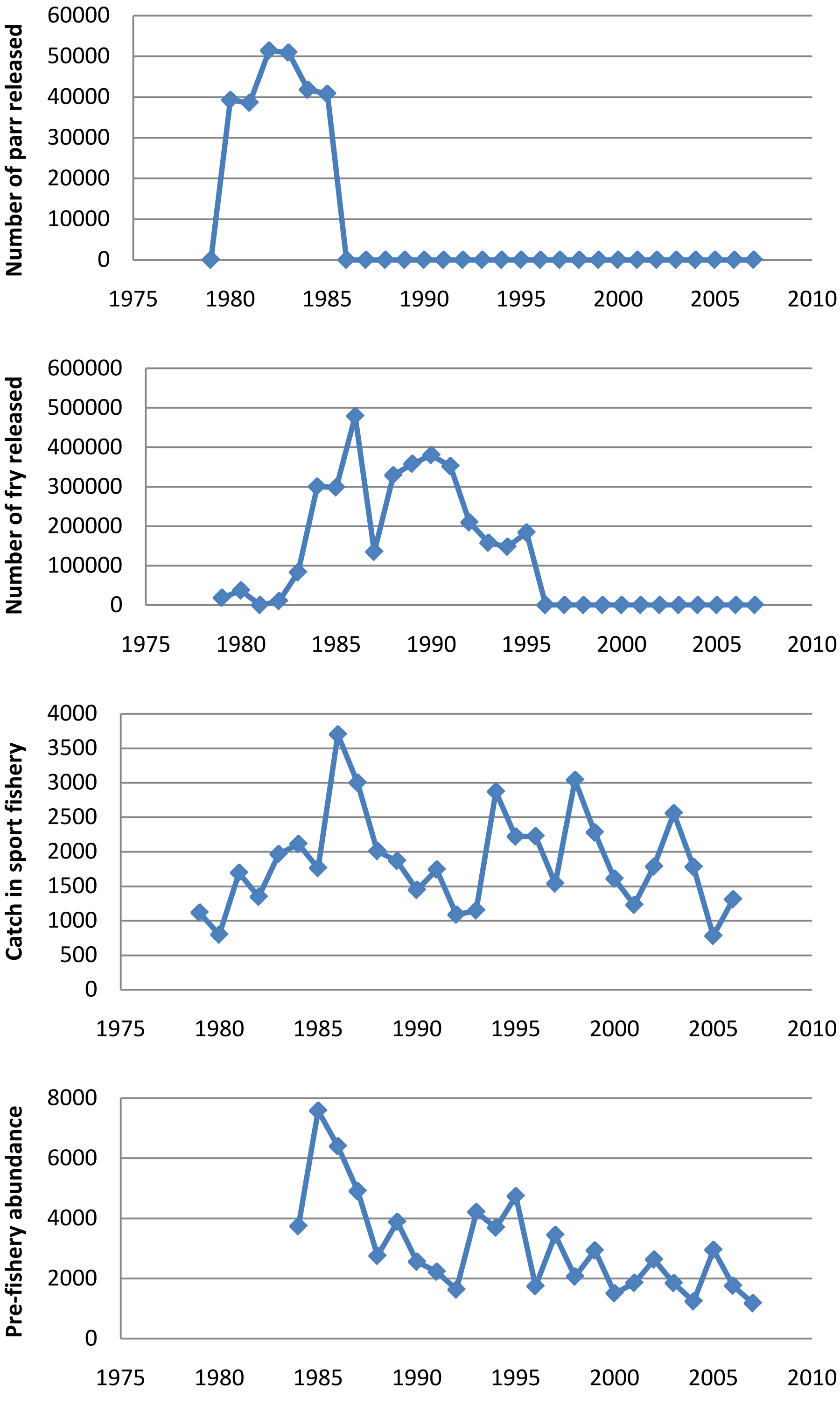

Figure 1. The number of hatchery parr and fry released and the abundance of steelhead as reflected in the sport fishery and as estimated prior to sport and interception fisheries.

Table 2. Escapement and exploitation rate data.

Escapement Year	Total escapment wild and hatchery	Fishery Year	Mortalities in sport fishery (kept+0.05*released)	Annual exploitation rate in bycatch fisheries	Estimated prefishery abundance	Annual exploitation rate in sport fishery	Total annual exploitation rate
1979		1978					
1980		1979					
1981		1980					
1982		1981					
1983		1982					
1984	1115	1983	1031	0.43	3736	0.28	0.70
1985	3514	1984	838	0.43	7576	0.11	0.54
1986	2326	1985	1349	0.43	6396	0.21	0.64
1987	1675	1986	1141	0.43	4902	0.23	0.66
1988	1500	1987	80	0.43	2750	0.03	0.45
1989	1671	1988	558	0.43	3881	0.14	0.57
1990	1200	1989	267	0.43	2554	0.10	0.53
1991	1200	1990	77	0.43	2223	0.03	0.46
1992	900	1991	36	0.43	1629	0.02	0.45
1993	2955	1992	36	0.29	4207	0.01	0.30
1994	2660	1993	128	0.24	3688	0.03	0.28
1995	2591	1994	129	0.43	4734	0.03	0.45
1996	1019	1995	133	0.34	1738	0.08	0.41
1997	3000	1996	69	0.11	3447	0.02	0.13
1998	1470	1997	114	0.23	2061	0.06	0.29
1999	2500	1998	97	0.11	2930	0.03	0.15
2000	1310	1999	53	0.09	1505	0.04	0.13
2001	1700	2000	37	0.06	1851	0.02	0.08
2002	2300	2001	57	0.10	2626	0.02	0.12
2003	1500	2002	90	0.14	1846	0.05	0.19
2004	1000	2003	57	0.15	1237	0.05	0.19
2005	2300	2004	23	0.21	2948	0.01	0.22
2006	1500	2005	45	0.12	1756	0.03	0.15
2007	930	2006	54	0.16	1176	0.05	0.21

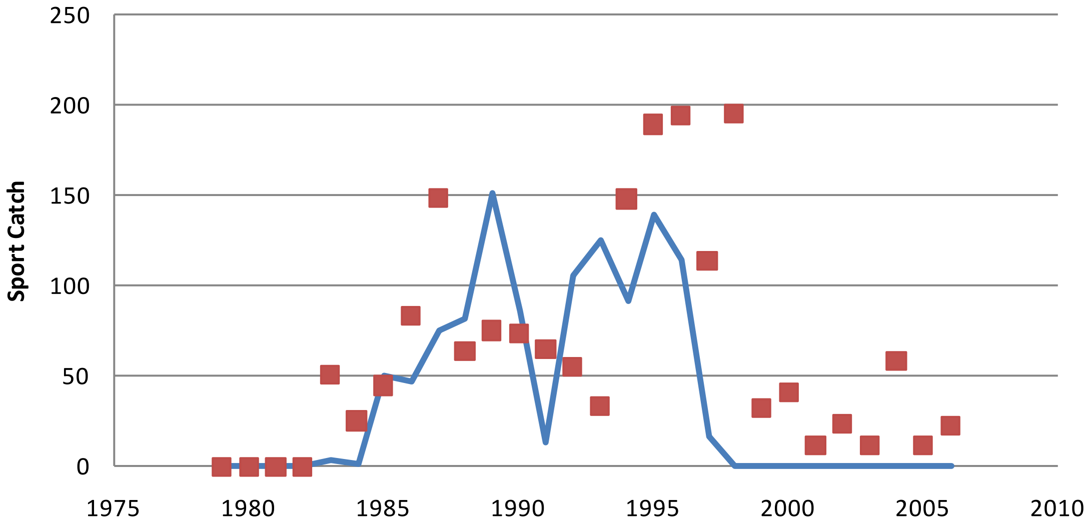

Figure 2. Predicted (line) and observed (squares) catches of marked hatchery steelhead in the Thompson sport fishery assuming a fixed age structure of 80% five-year-olds and 20% six-year-olds.

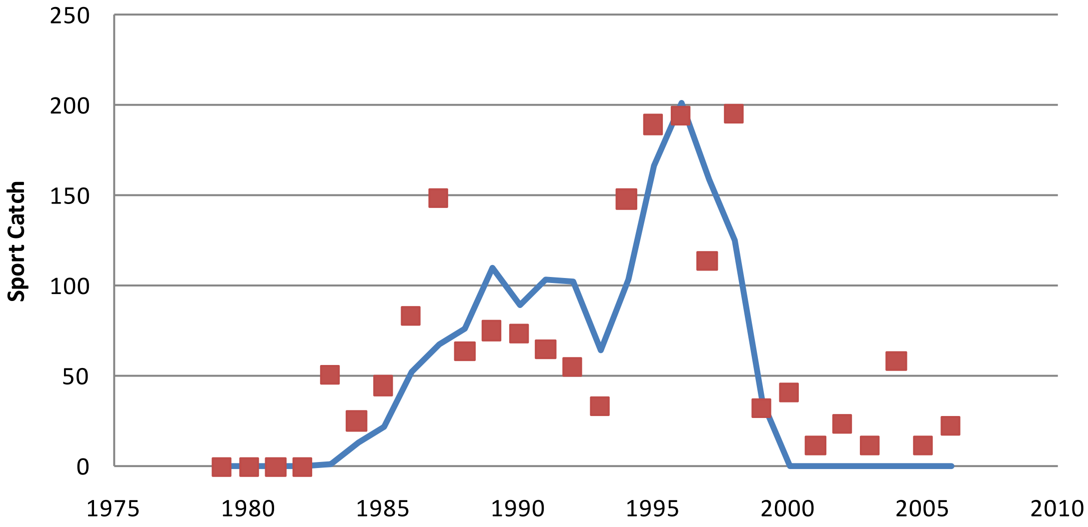

Figure 3. Predicted (line) and observed (squares) catches of marked hatchery steelhead in the Thompson sport fishery given no assumption about age structure other than it is constant. The constant age structure of "best fit" consists of 0.18, 0.17, 0.39, 0.26 age 4-7 respectively.

Table 3. Expected returns of marked and unmarked hatchery steelhead.

Escapement Year	Expected adult returns from stocked parr	Expected adult returns from stocked fry	Total Expected Returns of Marked and Unmarked Hatchery Steelhead
1979			0
1980			0
1981			0
1982			0
1983			0
1984	0	15	15
1985	88	34	122
1986	108	8	116
1987	137	8	145
1988	143	70	213
1989	122	263	384
1990	115	305	420
1991	23	453	475
1992	0	208	208
1993	0	296	296
1994	0	360	360
1995	0	384	384
1996	0	366	366
1997	0	243	243
1998	0	172	172
1999	0	153	153
2000	0	181	181
2001	0	38	38
2002	0	0	0
2003	0	0	0
2004	0	0	0
2005	0	0	0
2006	0	0	0
2007	0	0	0

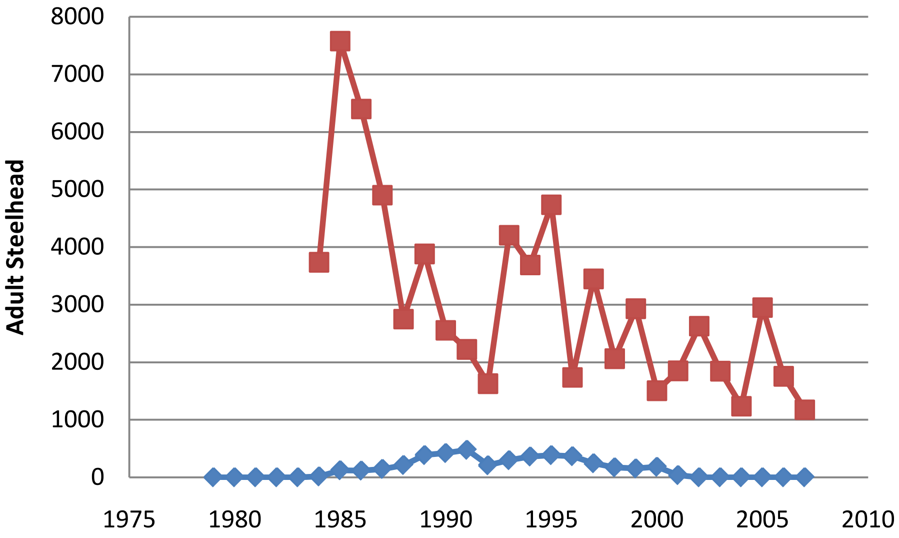

Figure 4. Total pre-fishery abundance of adult steelhead (squares) in comparison to the expected return of marked and unmarked hatchery adult steelhead (diamonds).

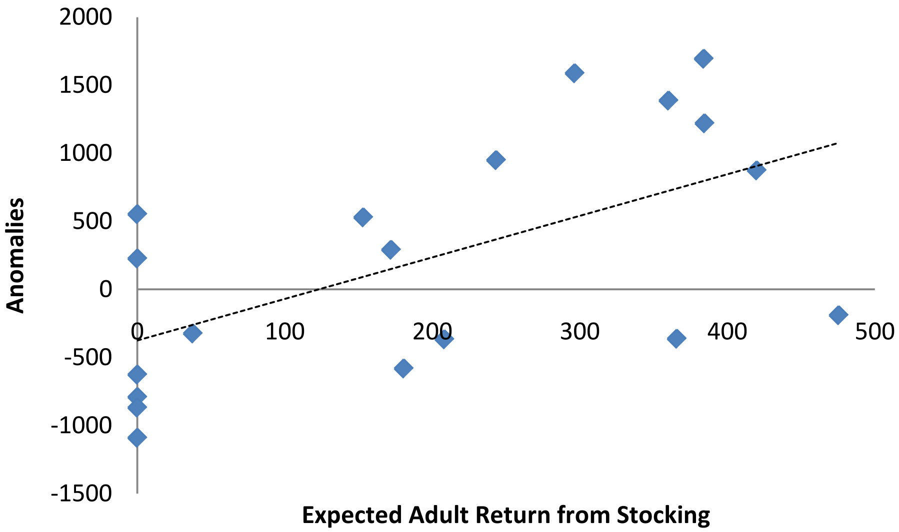

Figure 5. The relationship between adult recruitment anomalies and expected return of stocked steelhead.

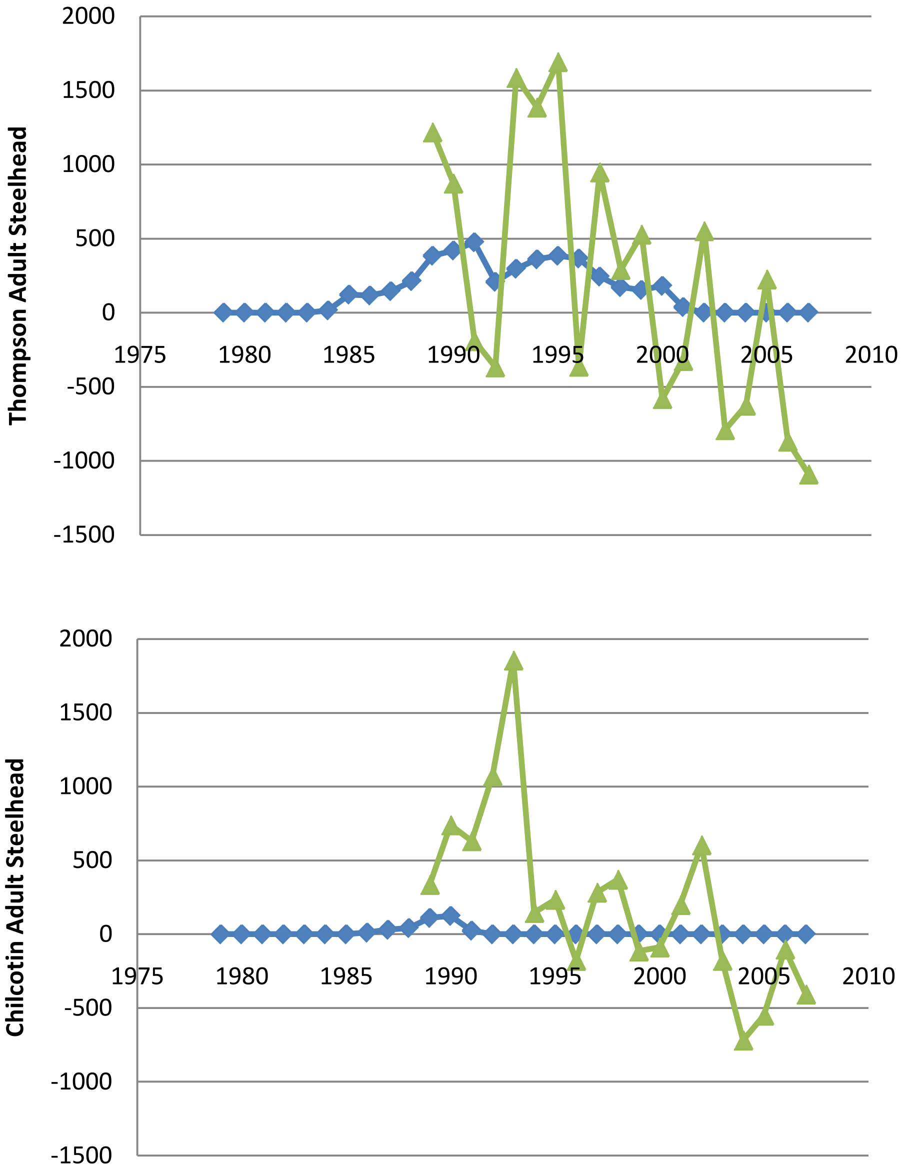

Figure 6. Adult recruitment anomalies (triangles), plotted according to the predominant return year, in comparison to the expected return of marked and unmarked hatchery adult steelhead (diamonds) for both the Thompson stock (top graph) and the Chilcotin stock (bottom graph).

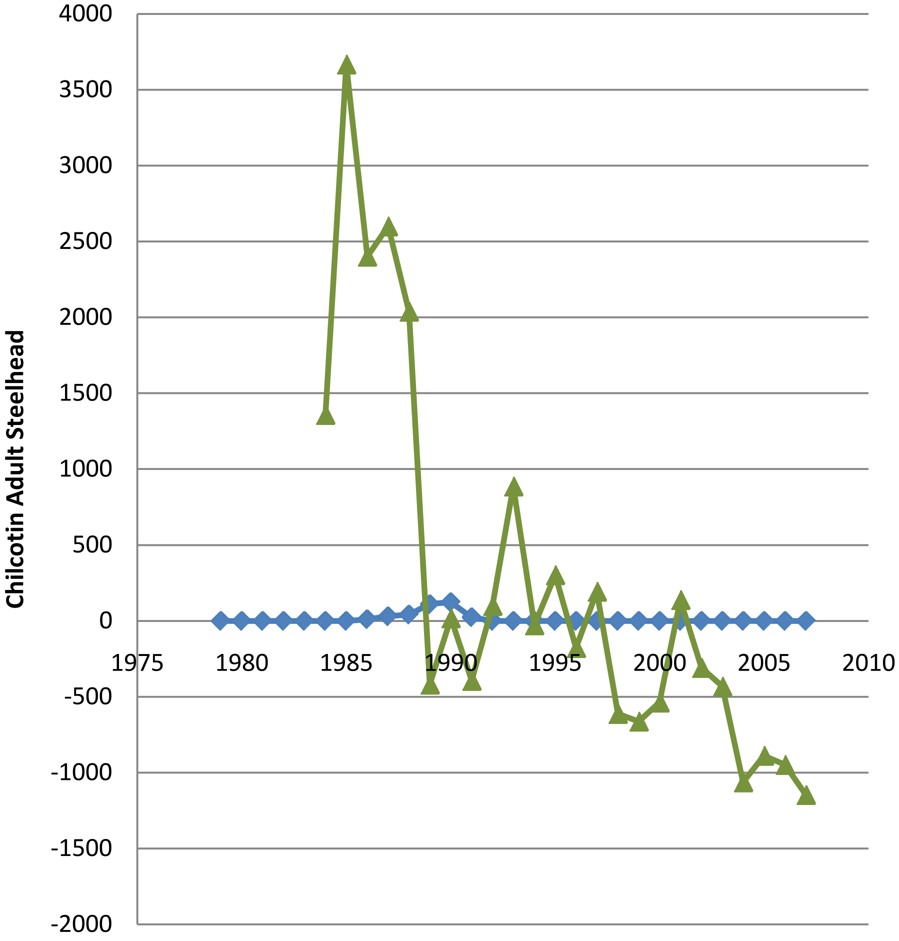

Figure 7. Adult recruitment anomalies (triangles) dating back to the high marine survival period of the mid 1980's, plotted according to the predominant return year, in comparison to the expected return of marked and unmarked hatchery adult steelhead (diamonds) for the Chilcotin.