Oncorhynchus mykiss population viability in Lapwai watershed: the importance of small-scale watersheds on basin-wide population dynamics.

Introduction

Steelhead (*Oncorhynchus mykiss*) are in serious decline throughout large, if not all, portions of their range. Listing on the Endangered Species Act (ESA) in the 1990's has resulted in several projects aimed at restoring the long-term viability of populations on a basin-wide scale. The need to focus on small scale populations at the sub-basin and watershed level has been recognized as an important step in restoring populations at the basin-wide scale because often times many small-scale populations are affected in a single area with the potential for additive or synergistic population declines. The Lapwai watershed in the Clearwater River basin is one such small-scale population that has recently been marked as a potentially important source of steelhead productivity. Water withdrawal has been recognized as a potential cause of steelhead population decline in the Lapwai watershed with potential implications for viability of the entire Clearwater basin population. The Bureau of Reclamation (BOR) owns a series of diversion dams and irrigation canals in the watershed. A recent ESA Biological Opinion (BO) placed a focus on the BOR owned canal system and the potential effects of this canal system on the viability of the steelhead population in the Lapwai watershed.

The BO requires minimum discharge over the diversion dams in the Lapwai watershed. Reduced flows in tributary streams have the potential to affect spawning success, juvenile survival and juvenile growth, all of which reduce the overall reproductive capacity of a population. Thus, the BO emphasizes the potential importance of small population units as well as the fact that habitat degradation is widespread amongst many of the small population units in the basin. In this situation, an understanding of meta-population (source-sink) dynamics becomes necessary to properly assess the viability of the basin-wide population. On the surface a watershed may appear to be a highly productive component of the basin fishery; however, upon closer investigation, the watershed may turn out to be a sink in which natural reproduction is low and immigration from more productive watersheds is high. In this case resource allocation may be shifted toward conserving relatively more important source habitats in the short run to maintain overall population viability.

A comprehensive analysis of the Clearwater River basin steelhead population is difficult due to the paucity of both historical and current data for the basin. We gathered any evidence we could find on population trends of the Clearwater River basin as a whole as well as the population trends of the Lapwai watershed. We were able to make rough estimates of the population growth rate and current population size of steelhead in the Clearwater River basin as well as the current population size of steelhead in the Lapwai watershed. To inform our estimates of steelhead population parameters, we researched current and historic trends in habitat condition in the Clearwater River basin and Lapwai watershed. The main product of this report is the synthesis of our habitat quality estimates and our steelhead population parameters into a generalized model that considers source-sink dynamics of smaller population units to estimate the viability of each population unit as well as the viability of the basin-wide steelhead population. We use parameters specific to the Lapwai watershed wherever possible in an effort to increase the power of the model to predict specifically the fate of the Lapwai watershed.

Habitat Description

The Clearwater River basin covers over 5.8 million acres and is located in north central Idaho. The drainage flows predominately east to west with many tributaries flowing north or south. The basin can be broken into 5 watersheds: The North Fork Clearwater River, the South Fork Clearwater River, the Selway River, the Lochsa River, and the main stem Clearwater River. Lapwai Creek is located in the main stem Clearwater River watershed. These basins possess unique ecological characteristics, land uses, and proportions of ownership. In this section, a detailed description of the Lapwai Creek drainage will be followed by brief descriptions of the sub-basins to develop an overall view of the Clearwater River basin from its headwaters along the Idaho-Montana border down to its outlet near Lewiston, Idaho.

The most comprehensive review of fish habitat done in the Lapwai watershed (including Lapwai, Sweetwater, Mission and Webb Creeks) was conducted by Kucera et al.(1983). Although this information is dated it is the most complete assessment on habitat essential to aquatic biota in Lapwai, Sweetwater, Mission and Webb Creeks. The main habitat concerns expressed about the Lapwai watershed are high annual flow variation, low summer flows, high summer temperature, sedimentation, and lack of instream cover (Kucera et al. 1983; Fuller et al. 1985).

High annual flow variation is largely a result of change in land cover and land use. In the Lapwai watershed the land use is comprised of 1.6% urban/rural use, 32% forestry, and 66% agricultural and range (Cichosz et al.). Croplands dominate the lower watershed, while forestry predominates in the upper watershed. The Idaho Department of Fish and Game found when modeling historic vs. current peak discharges in Lapwai Creek that the model estimated a 267% increase in the 10-year,24 hour peak discharge, increasing it from 1,800 cfs under natural historic land cover conditions to 6,600 cfs under current land cover conditions (Fish and Game et al. 1994). Alterations such as this affect sediment transportation and deposition patterns and water temperatures which in turn can negatively impact steelhead and other aquatic biota.

Low summer flows in the Lapwai watershed in large part are due to surface water withdrawals for irrigation. The most significant withdrawals come from Webb, Sweetwater and Captain John Creeks by the LOID (Lewiston Orchard Irrigation District) all of which directly affect flows in Lapwai Creek. USGS streamflow gages located in the watershed show that Webb Creek has been dewatered during summer months every year on record starting in 2002, Sweetwater Creek has been below 1 cfs 5 times in previous seven years, and Lapwai Creek has been below 2 cfs 10 times in the previous thirty years all during summer months (USGS 2008). This data is limited by the dates these sites were established, but it can be assumed that this happened just as frequent in past years since these large diversions systems have changed little over this time.

High summer temperatures are in direct relation to the low summer flows and lack of instream cover. Water temperature tolerance varies between species and life stages, for steelhead eggs and alevin temperature should not exceed 9-12ºC (Hicks 2000), steelhead juvenile rearing densities decrease linearly as temperature exceeds 17ºC (Frissel,1992), and steelhead adults die at temperature of 21-22ºC (McCullough 1999). Maximum temperatures in the Lapwai Watershed were recorded by Kucera et al. (1983) to be between 21.1 and 27.2ºC, all of which are insufficient for providing suitable habitat for steelhead at any stage in life.

Concerns of sedimentation issues in the Lapwai watershed are well founded with its high road density, land cover changes and the systems altered hydrograph. This issue was also looked at by Kuceral et al. (1983), who found that almost half of the substrates surface was lost to sand and fine material in the streams. This increase in sediment can drastically effect migration, spawning, incubation, emergence and rearing success of steelhead in the watershed (Furniss et al. 1991; MacDonald et al. 1991).

Lack of instream cover is a problem that increases from upstream to downstream in the Lapwai watershed. The forested areas of the upper watershed provide a diverse and multistory vegetative community while the lower watershed is comprised mainly of agricultural plant species providing little overhanging growth to shade the stream. This in turn only exacerbates problems like erosion of unstable banks, high water temperatures and provides no cover for aquatic biota.

Lapwai Creek is a major tributary within the lower main stem Clearwater River (CLRMA). Both water bodies are affected by similar land use and ecology. The CRLMA originates at the confluence of the South Fork Clearwater River and the Middle Fork Clearwater River. This confluence marks the start of the CRLMA basin (approximately 1.4 million acres). Majority of the land along the CLRMA is within private and tribal ownership. As the CLRMA continues westward, the vegetation changes quickly from dense forest to open dry grasslands and shrubs. The river is extremely wide with little in stream cover.

Little snow accumulation occurs and summers are predominately hot and dry. Agriculture, grazing, mining, forestry, and rural and urban development predominate along the river corridor and its tributaries contributing to the impairment of water quality parameters of temperature, sediment loading, and pollution.

Two Clearwater River basin head watersheds are the Lochsa River and the Selway River. These watersheds are similar in geology, climate, vegetation, land-use and proportion of land ownership. Combined they drain over 2 million acres of dense, moist forest. The surface soils are shallow humic and organic soil on top of granite. Landslides occur regularly in these drainages especially during spring melt off in fire affected areas. Precipitation occurs mostly in the winter as snow and snow packs can reach 14 feet in depth. Rain does occur the remaining months. Both the Lochsa and Selway Rivers are designated Wild and Scenic Rivers with the most of the Selway watershed is within the Selway Bitterroot Wilderness Area. These areas support a variety of multi-season recreational opportunities. The entire Lochsa watershed and the lower Selway watershed are managed for timber harvesting. The Selway watershed also supports grazing and mineral extraction. Land ownership is predominately US Forest Service (97%) with a small percentage of State of Idaho, private, and Plum Creek ownership. Overall, these basins are considered high quality streams according to IDEQ standards and provide high quality steelhead rearing habitat.

The North Fork Clearwater River drains approximately 1,561,260 acres. The basin receives most of its precipitation as snow in the winter months. The watershed is forested, contains many logging roads and is used for logging, grazing, and recreation. The lower watershed contains Dworshak Reservoir and there is no passage for migrating fish at Dworshak Dam. The water release from the dam occurs later in the year than high water regime before the building of the dam. The Clearwater National Forest manages 95% of the land. The remaining 5% is owned by the State of Idaho, private persons, or Plum Creek.

The South Fork Clearwater River drains approximately 876,000 acres of forested and agriculture lands. The upper reaches of the South Fork Clearwater River are forested while the lower reaches are considerable drier and contain open Ponderosa pine forest. Majority of the hydrology comes from snow melt in the high elevations and the lower elevations do not receive much rain in the summer months. Unlike the other headwater watersheds, the South Fork Clearwater has a substantial agriculture component, more development, and has many tributaries with 303(d) designation. Fifty-nine percent of the watershed is owned by national forest, 2% BLM, 1% Nez Perce Tribe, and 39% private persons. The South Fork Clearwater River supports forestry, mining, grazing, agriculture, rural/ urban development and recreation. These activities have reduced shading of surface water and contribute sediment into the streams. Five municipal wastewater treatment plants, urban development and industrial storm water runoff also contribute sediment and pollution into the streams.

Steelhead population trends in the Clearwater basin

Little data exists on actual wild steelhead populations in the Clearwater basin. We used current adult steelhead counts passing through Lower Granite Dam for estimates returning to the Snake River basin and adult counts from the Lewiston Dam prior to its removal in 1972 for estimates returning to the Clearwater. We further calculated an estimate of adult wild steelhead returning specifically to the CLRMA. Often, data collected on wild and hatchery steelhead numbers are lumped and we report estimated percent wild steelhead from total adult counts. We emphasize that these data should be used conservatively and only give the reader a general perspective on steelhead Clearwater watershed population trends.

Table 1 lists how estimates of wild Clearwater adult steelhead counts were derived. Counts of Snake and Clearwater Rivers were collected from adult steelhead counts passing through Lower Granite and Lewiston Dams, respectively. We estimated 27.1% of total Snake River adult steelhead counts were of wild origin. Further, we estimated 33.2% of wild Snake adult steelhead entered the Clearwater basin.

When given total Clearwater River adult steelhead counts, we calculated 38.9% of these were of wild origin (Mallet 1974, Lukens 1984, and Olsen 1992).

Table 1. Data in year ranges as found from citations. Counts shown are yearly averages using data from stated range Counts are from the Snake River (Lower Granite Dam) and Clearwater basins (Lewiston Dam) for total, hatchery, and/or wild adult steelhead. Symbols denote derived numbers using ratios calculated in final column.

Years	Citation	Average Snake River Counts			Average Clearwater River Counts			Ratios derived from citation data
		Total	Hatchery	Wild	Total	Hatchery	**Wild**	
1962-1971	Mallet 1974	67940			22556		**8774****	22556/67940= 0.332, ratio of Clearwater to Snake
1973-1979	Lukens 1984				9799	5990	**3809**	5990/9799 = 0.389, ratio of Wild Clearwater to Total Clearwater
1980-1989	Olsen 1992	87480	63810	23670			**7858*****	23670/87480 = 0.271, ratio of Wild Snake to Total Snake
1992-2007	IDFG 2008	178691		48425*			**16077*****	

*multiplied Total Snake by 0.271 ratio
**multiplied Total Clearwater by 0.389 ratio
***multiplied Wild Snake by 0.332 ratio

To estimate the number of wild Clearwater River adult steelhead contributing to the CRLMA specifically, we used ratios of usable habitat for steelhead from the watersheds that comprise the Clearwater basin (Cichosz 2001, Table 33). Using these data we calculate the CRLMA constitutes 21.7% of the usable habitat in the entire usable Clearwater basin. We assume percent usable habitat corresponds to percent of adults returning to each watershed. We understand this is a gross generalization but believe it to be reflective of habitat quality for adult spawning salmonids. We therefore multiply this percent (21.7%) by the estimated numbers of wild Clearwater adult steelhead as derived from Table 1 (in bold) to derive a CRLMA-specific estimate (Table 2).

Table 2. Years with data found in literature and estimates of average yearly wild adult steelhead counts returning to the Clearwater basin and CRLMA watershed. CRLMA estimates derived by multiplying Clearwater basin numbers by 0.217 as derived from usable habitat data in Cichosz, 2001.

Years with data	Number of wild adult steelhead to Clearwater basin	Number of wild adult steelhead to CRLMA
1962-1971	8774	1904
1973-1979	3809	826
1980-1989	7858	1704
1992-2007	16077	3489

From our estimates for given years with data, we note a decline in average number of wild adult steelhead returning to the CRLMA watershed between 1962-1971 and 1973-1979. It is important to note the Lewiston Dam (located near the mouth of the Clearwater River, built in 1927), which included a fish ladder for steelhead passage, was removed in 1973 and may have been a factor for the initial decrease during this time. Throughout the 1980s the number of adults returning to the CRLMA increased and presently we estimate the highest adult returns to the area since beginning of data found in literature. Information prior to 1962 from the Clearwater basin would provide important insight to the possible effects of the Lewiston Dam on the wild adult steelhead returns and provide additional depth to presented data.

Steelhead Population trends in the Lapwai Watershed

The importance of the Lapwai watershed steelhead population to the CRLMA depends on several population parameters. Measurement or estimation of the population abundance and growth rate of Lapwai watershed steelhead relative to those of other watersheds in the CRLMA is required to assess the overall importance of Lapwai watershed to the CRLMA (McElhany et al. 2000). Unfortunately, there is very little historical data describing steelhead abundance and population growth in the watershed (Lohn, 2006).

Some anecdotal evidence suggests that the streams in Lapwai watershed were historically important producers of anadromous steelhead. Until about 30 years ago the Nez Perce Tribe operated a steelhead snag fishery in Mission Creek. The number of fish removed from this operation suggests that large numbers of adult steelhead were returning to Mission Creek to spawn (Johnson and Stangl 2000). In another anecdotal report, the Lewiston Morning Tribune documented numerous steelhead killed in a flash flood in late April, 1986. While these reports suggest that steelhead were historically present and perhaps abundant in Lapwai watershed, they do not offer the kind of information required to develop even a rough estimate of historic steelhead abundances or population growth rates. To overcome this dearth of historical data, later in this paper we present a model which considers realistically-bound watershed-specific estimates of population growth rate to estimate the importance of Lapwai watershed to the Clearwater basin.

Recent studies allow us to make more direct estimates of the current total abundance of steelhead in Lapwai watershed. Chandler and Parot (2003) and Chandler (2004) conducted a spatially extensive study of the abundance of steelhead throughout the Lapwai watershed. They conducted electrofishing passes on every stream kilometer along Lapwai, Mission, Sweetwater, and Webb Creeks. We combined the data from Chandler and Parot (2003) and Chandler (2004) with unpublished data collected in 2008 (Hartson) to produce an estimate of absolute steelhead abundance for all areas of the watershed reachable by anadromous fishes. We grouped relative estimates by attempting to maximize spatial proximity to associated absolute measures and minimize differences in the magnitude of the age structured relative and absolute abundance measures. Data collection methods and analysis is presented in Appendix 1.

If we make some simple assumptions about the proportion of anadromy and the survival of smolts to adulthood in Lapwai watershed, we can create a rough estimate of the input of Lapwai watershed steelhead to the entire CRLMA population. We will assume that the Lapwai watershed steelhead population is largely dominated by anadromous individuals. The high relative abundance of subyearling fish and near zero abundance of fish aged 2 years or older (Hartson, unpublished data; Chandler and Parot, 2003) supports this assumption. Based on historic measures of the age structure of smoltifying steelhead in the Clearwater basin (Whitt, 1954), we assume the proportion of each age class smoltifying is 15%, 75%, and 90% for subyearlings, yearlings, and fish aged 2 years or older respectively and we estimate survival of smolts to spawning age as 0.02, 0.04, and 0.08 for subyearlings, yearlings, and fish aged 2 years or older respectively. Under these population parameters, we expect the Lapwai watershed as a whole to return 1191 spawning adults (Table 3).

Table 3: Estimated number of juvenile Steelhead in Lapwai watershed during summer 2008, estimated age-structured proportion of juveniles in Lapwai watershed during summer 2008, estimated number of smolts leaving Lapwai watershed in spring 2009, and estimated number of 2009 smolts from Lapwai watershed returning as adults in subsequent years to the Clearwater-Lower Mainstem basin.

	Age 0	Age 1	Age 2+	Total
Number of juveniles in Lapwai watershed (summer 2008)	72,441	28,694	1568	102,703
Proportion of each age class in Lapwai watershed (summer 2008)	.70	.28	.02	1.0
Number of smolts leaving Lapwai watershed (spring 2009)	10,866	21,521	1,411	33,798
Number of 2009 smolts from Lapwai watershed returning as adults in subsequent years	217	861	113	1191

When we compare this number to our estimate from the previous section that adult returns to the CRLMA over the last 10 years have averaged 3489 individuals, we estimate that the Lapwai watershed produces around 34% of the total CRLMA returning adult steelhead population. We conclude that, despite its relatively small size, Lapwai watershed appears to be a very important source of anadromous steelhead and that failure of this fishery could potentially produce a noticeable effect on the steelhead population in the CRLMA.

Predictive Steelhead Abundance Model

As a framework upon which to ground a biological opinion on steelhead viability in the CRLMA and Lapwai Creek, a stochastic relative abundance model was created to characterize the population in terms of source/sink meta-population dynamics. The dynamics of subpopulations and their relative input to the growth of the population as a whole has been recognized as an important consideration both in the legal fight over the BOR/LOID water withdrawal plan and on overall steelhead population in the CRLMA and the Clearwater basin as a whole.

Due to the paucity of data for individual streams, and the complexity of a model for each stream in the Clearwater, the basic assumption of the model is that sub-basins can be assumed to interact with each other as if they are a single stream. To this end we utilized a simple model based on that set forth by Cooper and Mangel (1999) to model the relative abundance and population dynamics of salmon in a declining system. The basic equation is listed below:

$$N(i,t+1) = r(i,t)\left\{N(i,t)(1-f) + \sum_{j \neq i} s(j,i,t)\right\}.$$

$N(i,t)$ = the deme abundance in stream i in year t;
$r(i,t)$ = the per-capita reproduction in stream i in year t;
$s(j,i,t)$ = the number of fish that stray from their natal stream j to stream i in year t; and
f = the fraction of fish that stray from their natal stream (assumed equal for all demes).

Growth rate (r)is assumed to be determined by relative habitat ability with a baseline reproductive rate (z_0) and competing growth curves determined by z_1 and z_2 and limited by maximum and minimum constants for the decrease or increase in habitat (g and b).

$$r(i,t) = z_0 + g\left\{1 - e^{-z_1(i,t)}\right\} - b\left\{1 - e^{-z_2(i,t)}\right\}$$

A detailed description of the model application, data sources, extrapolations, and assumptions are listed in Appendix 2.

In constructing the model several relationships became clear. The Lower Selway and Lochsa were by far the most productive streams and thus were considered the prime sources within the overall population over a very wide range of poor habitat conditions (z_2). Thus, under most situations 2 of seven streams are sources (28%), much lower than the assumption of 60:40% assumed by Cooper () to be the ratio of a heavily impacted population.

As bad habitat (z_2) decreased, the CLRMA and South Fork eventually reach the point of becoming a population source. The two streams become sources at the same time meaning that the percentage of source streams jumps to 4 of 7 (60%). This switch has implications for steelhead populations. If habitat conditions are good enough that the CLRMA and South Fork Clearwater River are sources then population may be much more stable than has been thought. However, this is an unlikely scenario based on population trends. It also presents the possibility that focus on habitat restoration in these two sub-basins could provide a high return on investment in terms of population stability as they are next in line to become source populations if habitat improves.

Two model treatments were tested to examine the most interesting aspects of population dynamics given a declining system as a whole. The first was the condition in which a source population is allowed to degrade at a higher rate than the whole population. In the case of Lapwai Creek, the model result shows if the BOR/LOID project is left at current water withdrawal levels over the long term, then increasing habitat destruction relative to the other watersheds will occur.

The second model treatment tested an assumption that all watersheds in the system were sinks. It is possible for all populations to be sinks in a system due to habitat degradation. Populations can still persist for long periods (Cooper and Mangel), however they are doomed to decrease to extinction. The model exemplified this for the entire Clearwater basin.

One interesting case for Lapwai Creek would be if habitat restoration were successful despite Lapwai being a sink population. Overall habitat degradation in that case would be lower than that for the basin as a whole. When a model was run assuming that the Lower Clearwater degraded at a lower rate (2% vs. 5%) it was shown that despite starting as a sink the sub-basin became a relative source around year 2020. This subsequent increase in population due to improved habitat created a 15% increase in maximum abundance and helped to stabilize the population. The results could be expected to climb as relative habitat quality increases beyond this point as well.

Overall this data is encouraging and forms the basis of our opinion that the meta-population structure of steelhead in the whole Clearwater basin provides a good return on investment for effort expended to improve habitat in the Lapwai watershed.

From our data it appears that the Lapwai watershed has the potential to be a strong source population for the overall Clearwater basin as well as within the CRLMA. Unfortunately, the data is incomplete to show definitively that it is or is not a source. Still, the Lapwai watershed provides a large percentage of the steelhead adults in the CRLMA and thus habitat improvements could help to lift the CRLMA to the level of a source.

Based on the models in the worst case scenario, if the Lapwai watershed is allowed to stay the same or degrade, we can assume that it will have a deleterious effect on the entire region, albeit small. The CLRMA, however, could have a large stabilizing impact on the entire Clearwater basin population if it were to become a source. Currently, only 2 substantial source populations (Selway and Lochsa watersheds) are present in the Clearwater basin. Adding another, even at a lower rate would increase extinction time, and allow time for overall habitat improvement, and would also add significantly to the abundance of steelhead. In this instance it would be biologically advisable to improve the Lapwai watershed habitat in the hopes of stabilizing the entire Clearwater basin meta-population through the addition of the CRLMA as another source habitat. This will likely improve the outlook of the steelhead population in the future, a major goal for many stakeholders.