

THE EFFECT OF IRRIGATION DIVERSIONS ON THE MOUNTAIN WHITEFISH
(*PROSOPIUM WILLIAMSONI*) POPULATION IN THE BIG LOST RIVER

by

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ABSTRACT

The Effect of Irrigation Diversions on the Mountain Whitefish (*Prosopium williamsoni*)
Population in the Big Lost River

by

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Management agencies documented a decline in the mountain whitefish (*Prosopium williamsoni*) population on the Big Lost River, and unscreened diversions were recognized as a potential factor for this decline. Research suggests the Big Lost River mountain whitefish population is genetically unique, and it has been petitioned for protection under the Endangered Species Act. In 2007, a basin-wide synopsis of diversions was conducted to describe relative entrainment and identify diversions that entrained the most mountain whitefish. This larger scaled synopsis facilitated a more precise assessment of entrainment by a subset of diversions in 2008. In 2008, the volume that was diverted and the available stream-flows were assessed to identify correlations between discharge and increased entrainment. Lastly, a stage-structured population matrix model was used to describe the potential effect that entrainment is having on the mountain whitefish population. Entrainment was evaluated in canals using multiple-pass electrofishing depletions in conjunction with block-nets. Entrainment was estimated

using simple or stratified random population estimates. Entrainment varied widely among diversions and between water years. Variations in entrainment were attributed to seasonal patterns, population densities, and the physical characteristics of the diversion. A positive correlation was identified ($R^2 = 0.81$) between the number of mountain whitefish entrained and the volume of water diverted annually. I observed substantial numbers of fish entrained by two diversions on the upper Big Lost River. I illustrate how reducing entrainment at these diversions will increase recruitment to adulthood and increase the viability of the population overall.

(65 pages)

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INTRODUCTION

Fish entrainment by irrigation diversions has been a concern for fisheries biologists since the late 1800's (Clothier 1953). Despite early identification of the problem, the population effects of entrainment by diversions remain poorly understood (Moyle and Israel 2005).

Irrigated agriculture accounts for the largest use of freshwater in the world (Oki & Kanae 2006). In the year 2000, agricultural water use accounted for 40% of freshwater consumption in the U.S.A. (Huston et al. 2004). Research examining the effects of large dams has led to modifications in design and operation to minimize the impact on associated species and habitats (Collier et al. 1996). A better understanding of the impacts that irrigation diversions have on fish populations may lead to modifications of diversion head gates to minimize entrainment (Post et al. 2006; Carlson and Rahel 2007; Gale et al. 2008). With the possibility that global warming could decrease the availability of freshwater resources, and with half of the world's population located in water stressed areas, there is a need to understand and account for such disturbance (Oki & Kanae, 2006).

Because of their economic value and migratory behavior, anadromous species have been the focus of most entrainment studies (Fleming et al. 1987). Much of the research has focused on the design and evaluation of fish screens, a mechanism designed to prevent fish from being diverted into canals (Gebhards 1959; Gale et al. 2008). Evaluations of entrainment of inland fish populations have recently increased, but few

commonalities have been identified, and many issues still need to be addressed (Carlson and Rahel 2007).

The factors that affect entrainment among diversions are not well understood (Carlson and Rahel 2007). The physical characteristics of the diversion, and the amount of water diverted, however, have been recognized as potential factors (Spindler 1955; Carlson and Rahel 2007). Location of the diversion within a basin, as well as time of year, may also help explain differences in entrainment among diversions (Schrank and Rahel 2004; Carlson and Rahel 2007). Spatial differences in entrainment are a function of population density, while temporal variations are attributed to seasonal fish movements (Schrank and Rahel 2004).

Among inland salmonid species, the entrainment of mountain whitefish (*Prosopium williamsoni*) has rarely been considered because of their lower societal value (Meyer et al. 2009). Estimations of mountain whitefish entrainment have been documented in some cases, usually in conjunction with other salmonid species (Clothier 1953, 1954; Post et al. 2006; Gale et al. 2008).

Mountain whitefish are members of the salmonid family (subfamily Coregoninae; Northcote and Ennis 1994). In the United States, the native range of this species extends from the Colorado River basin throughout the Rocky Mountain States north to the Mackenzie River basin (Behnke 2002; Meyer et al. 2009). Mountain whitefish are one of the most abundant game fish in Idaho (Simpson and Wallace 1982). Mountain whitefish are a long-lived species with individuals living up to 29 years (Northcote and Ennis 1994). Previous research in the Big Lost River basin indicates most mountain whitefish

over 250 millimeters (mm) are mature, but all fish less than 200 mm are not (Corsi and Elle 1989).

Migrations associated with mountain whitefish spawning behavior vary among watersheds. Some populations migrate long distances to spawn in tributaries, while other populations move very little (Northcote and Ennis 1994). Spawning occurs in late fall when water temperatures approach 6°C (Simpson and Wallace 1982). Spawning occurs at night or during low-light periods with fish broadcasting their eggs and sperm in riffles, over gravel substrates (Northcote and Ennis 1994). Hatching occurs the following spring, in March and April (Northcote and Ennis 1994). After hatching, fry are thought to occupy lateral habitats and low velocity areas which makes them more vulnerable to entrainment at this stage in their life-history (Northcote and Ennis 1994). Previous surveys of canals in the Big Lost River basin have documented high numbers of juvenile mountain whitefish mortalities at the end of the irrigation season (IDFG 2007).

In the Big Lost River basin, mountain whitefish appear to have been isolated for a substantial period of time. Recent studies that addressed the range-wide genetic and phylogeographic structure of mountain whitefish provide important insight into the origin of the population in the Big Lost River basin. Whiteley et al. (2006) suggests that three broad genetic assemblages of mountain whitefish occur across the species range. Of the assemblages identified, the mountain whitefish in the Big Lost River are the most genetically divergent population and are most closely related to the Upper Snake River assemblage (Whiteley et al. 2006). Campbell and Kozfkay (2006) suggest mountain whitefish in the Big Lost River may have been isolated for approximately 165,000 - 330,000 years.

Mountain whitefish abundance and distribution in the Big Lost River basin has declined in recent years. Idaho Department of Fish and Game (IDFG) and the United States Forest Service (USFS) conducted a thorough assessment of mountain whitefish abundance and distribution in the Big Lost River basin between 2002 and 2005 (IDFG 2007). Their results indicate that mountain whitefish occupied approximately 24% of their historical range (IDFG 2007). Adult mountain whitefish (>200 mm) abundance in the entire basin was estimated to be 2,742 fish, or approximately 1.5% of historic abundance (IDFG 2007). In addition to habitat modification and fragmentation of the population, entrainment of mountain whitefish by irrigation diversions is recognized as a potential factor for the decline in mountain whitefish abundance in the Big Lost River (IDFG 2007). Given the unique genetics and low abundance of mountain whitefish in the Big Lost River, it is important to better understand how susceptible this population is to the effects of entrainment (IDFG 2007). Furthermore, private organizations have petitioned the United States Fish and Wildlife Service (USFWS) to list this population under the Endangered Species Act (USFWS 2007).

The goal of this project was to quantify entrainment by irrigation diversions then assess the impact of entrainment to mountain whitefish populations in the Big Lost River basin above and below Mackay Reservoir. The first objective was to obtain a basin-wide synoptic assessment of diversions to identify those diversions entraining the most fish.

The second objective was to estimate the number of whitefish entrained over a range of different diversions. In order to estimate entrainment, recent studies identify the necessity to understand mountain whitefish behavior within the canals (Schrank and Rahel 2004; Post et al. 2006; Gale et al. 2008). There were three possible fates for

entrained fish: 1) they could move down the canal and occupy a particular reach where they will perish when the diversion is shut off at the end of the season, 2) they could move to the extremities of the canal where they will perish in a field or when the diversion is shut off, or 3) they may return to the river. Understanding possible movement patterns is important if entrainment estimates are not to be biased.

The third objective was to identify physical factors of diversions that resulted in increased entrainment of fish. Spindler (1955) identified several flow conditions that might contribute to increased fish entrainment. Diversions located on an outside bend of the river, diversions with a dam, and the location of the diversion in relation to river flow direction are all physical characteristics considered to increase entrainment (Spindler 1955). Understanding which physical characteristics are correlated with increased entrainment will help identify the entrainment potential of diversions not included in this assessment.

The last objective was to describe the effect diversions are having on the mountain whitefish population by comparing current population estimates with our entrainment estimations and incorporating them into a population model. Understanding the population effects of entrainment facilitates the prioritization of management actions and allows for the anticipation of population benefits where entrainment is reduced.

Study Area

The Big Lost River is the largest (with a watershed covering 5,159 km²) of several hydrologically isolated streams located in south-central Idaho, collectively termed the Sinks Drainages or Lost Streams (IDFG 2007). The Big Lost River originates in the

Pioneer, Boulder, Lost River, and White Knob mountain ranges and flows onto the Snake River Plain where it terminates at the Big Lost River Sinks (IDFG 2007). The climate within the basin ranges from an arid, montane climate with a mean annual precipitation of approximately 200 mm at elevations near 1,500 meters (m) to alpine climates with over 1,000 mm of precipitation at elevations above 3,500 m. The Big Lost River watershed is comprised primarily of federally managed land (83%), with lesser amounts of private (15%) and state (2%) lands (IDFG 2007). Agriculture is the dominant land use on private lands, with cattle grazing and recreation the primary uses of Federal land (IDFG 2007).

A major alteration of the Big Lost River occurred with the construction of Mackay Dam. Mackay Reservoir is an irrigation water storage facility which first stored water in 1918 (IDFG 2007). Since then, the river below Mackay Dam has been regulated to accommodate irrigation demands. As a result, the hydrograph for the lower Big Lost is one with lower than natural winter and spring flows, but where late-summer and early-fall flows are higher than pre-dam conditions. Water is stored from the end of each irrigation season through the beginning of the following season (generally mid-October to the end of April).

Twelve species of fish have been documented in the basin, including the species of interest for this project, the mountain whitefish (MWF; Gamett 2003). Of these species, it is thought that only three species – the mountain whitefish, shorthead sculpin (*Cottus confusus*), and Paiute sculpin (*Cottus beldingii*), are native to the Big Lost River basin (Gamett 2003). The mountain whitefish is the only salmonid indigenous to the Big Lost River basin (Gamett 2003).

There are a total of 54 diversions on the Big Lost River (Gregory 2004). Irrigation diversions independently impact mountain whitefish populations above and below Mackay Reservoir. These two populations are isolated by an ephemeral river reach, and the impoundment. The mountain whitefish population abundances in the Big Lost River basin were estimated in 2007 by IDFG and USFS. The population from the Chilly diversion (located 24 kilometers (km) upstream from Mackay Reservoir) upstream to the confluence of the North Fork and the East Fork of the Big Lost River (total distance of 24.7 km) was estimated at 7,209 mountain whitefish larger than 200 mm (Garren et al. 2009). Between the Chilly diversion and Mackay Reservoir, the river runs intermittently during the summer. Because flows are not sustained throughout the summer, populations in the Big Lost River between the Chilly diversion and Mackay Reservoir were not assessed.

From Mackay Dam, downstream 32.6 km to the 3-in-1 diversion, there were an estimated 2,051 mountain whitefish larger than 200 mm (Garren et al. 2009). In dry years, the Big Lost River can be entirely diverted at the 3-in-1 diversion. Although entrainment of mountain whitefish has been documented in canals downstream of the 3-in-1 diversion, this portion of the population is entirely lost whether the fish remain in the main river or in irrigation canals because both are eventually dewatered. Therefore, no effort was given to estimation of the population downstream of the 3-in-1 diversion.

METHODS

Study Site Selection

The mountain whitefish populations in the upper and lower Big Lost River are essentially independent. Therefore, the magnitude of entrainment depends in part upon the population density in these two segments (Carlson and Rahel 2007). To assess both populations, sampling was stratified into two strata – from the Chilly diversion upstream to the confluence of the North Fork and the East Fork of the Big Lost Rivers (hereafter referred to as the upper Big Lost), and downstream of Mackay Dam to the 3-in-1 diversion (hereafter referred to as the lower Big Lost). To avoid inconsistencies with water availability, no effort was given to evaluating entrainment downstream of the 3-in-1 diversion, or from the Chilly diversion to Mackay Reservoir. This resulted in an underestimate of the total number of fish lost to both populations while allowing for a more accurate assessment of the remaining diversions.

Objective 1 – A basin-wide synopsis of diversions

Diversions in the upper and lower Big Lost vary in size, position, location, and other physical characteristics. The number of fish entrained by a diversion varies according to these characteristics (Spindler 1955). To account for variability among diversions, 12 diversions over the range of physical characteristics were assessed in 2007.

We began by identifying 22 diversions within the two study areas that were thought to entrain mountain whitefish (Table 1). These diversions were then stratified based on the volume of water diverted, the physical characteristics of the diversion

(Spindler 1955), and preliminary entrainment surveys (IDFG, unpublished data; USFS, unpublished data). The volume of water diverted was assessed using data available from Idaho Department of Water Resources (IDWR) Water District #34. The volume of water diverted was determined by the maximum amount and the average duration that water had been diverted between the years 2005 to 2007 (IDWR 2007).

For three years prior to the commencement of this project, preliminary surveys had been conducted in a subset of diversions by the IDFG and the USFS. Data consisted of the number of fish salvaged from ephemeral pools within canals after diversion head gates were closed at the end of the irrigation season. In 2006, the USFS conducted a pilot study during the irrigation season to assess sampling techniques and to help identify which diversions entrained the most fish.

Final stratification of diversions was based on three groups of suspected entrainment: high, moderate, and low (Table 1). Initial stratifications were based on the number of mountain whitefish thought to be entrained. Diversions classified as having high or moderate entrainment were sampled more intensely than diversions classified as having low entrainment.

For analytical purposes, the Chilly and the 3-in-1 diversions were characterized as terminal diversions. They are referred to as terminal because at these two diversions, if fish are not diverted and move downstream in the river, their fates are unclear. Both diversions have large dams, and fish passage upstream around these dams had not been established. During dry years, the river can be completely dewatered below each diversion. This characteristic identifies potentially high entrainment at these diversions. From a population perspective, however, fish that are in the river below the diversion

have the same fate as those fish that become entrained in the canal: They are lost from the population.

Within canals, the density of fish differs with habitat complexity. In general, habitat within canals is simple. Exceptions exist near the head gates and check structures where flow conditions and substrates increase refugia used by fish (Lancaster and Hildrew 1993). Check structures are prevalent within canals in the Big Lost River basin. Check structures are used for grade control, to prevent scour of the canal bed, or to provide a known width and depth so that discharge can be measured within the canal. To account for the variations in fish density, I stratified canals into complex habitat and simple habitat. Sample reaches identified as complex habitat were located directly downstream of a head gate, check structure, or a culvert. Complex habitat was characterized by greater depths, turbulent flow, and variable substrates with larger interstitial spaces. Simple habitat is characterized by shallow, narrow reaches with relatively homogenous substrate sizes, and uniform flow. Simple habitat characterizes the majority of all canals.

Evaluating the range of unscreened irrigation diversions in 2007 helped identify the characteristics that cause variations in entrainment among diversions (high, moderate, and low; Table 1). This wider scaled assessment was used to focus efforts in 2008 on three diversions in each population strata, representing each level of expected entrainment (Figure 1).

Table 1. Irrigation diversions considered for this project occur on the main stem Big Lost River from the 3-in-1 diversion upstream to Mackay Dam (Lower), and from the Chilly diversion upstream to the confluence of the East Fork and North Fork Big Lost Rivers (Upper). Criteria for selection and suspected entrainment potential are listed below.

Diversion Name	Population Segment	Selected	Entrainment Stratification	Criteria for Selection
3-in-1	Lower	Yes	High	High volumes of water, Preliminary surveys
Beck	Lower	Yes	High	High volumes of water, Preliminary surveys
Spring Creek	Lower		Low	Low volumes of water diverted
Sutter	Lower		Low	Low volumes of water diverted
Vanous	Lower		Low	Low volumes of water diverted
Burnett	Lower	Yes	Moderate	Very large, sampling probability would be low
Darlington	Lower	Yes	Moderate	High volumes of water on an outside bend of parent reach
Swauger	Lower	Yes	Low	Preliminary Surveys
Streeter	Lower		Low	Low volumes of water diverted
Sharp	Lower	Yes	Low	Preliminary Surveys
Chilly	Upper	Yes	High	High volumes of water, Preliminary Surveys
Bradshaw	Upper		Low	Low volumes of water diverted
Neilsen	Upper	Yes	High	High volumes of water, Preliminary Surveys
Johnson/Hatmaker	Upper		Low	Nearly dry (5-23-07)
Thalman/Hunter	Upper		Low	Stagnant low flows
Anderson	Upper		Low	Stagnant low flows
Split	Upper		Low	No canal associated
Bartlett/Bitton	Upper	Yes	Low	Dry (5-23-07)
Bradshaw upper	Upper	Yes	Moderate	Moderate volumes of water diverted
Kent	Upper	Yes	Low	Dry (5-23-07)
Howell	Upper	Yes	Moderate	Fringe habitat for 0's on an outside bend of parent reach
Sorenson	Upper		Low	Dry (5-24-07)

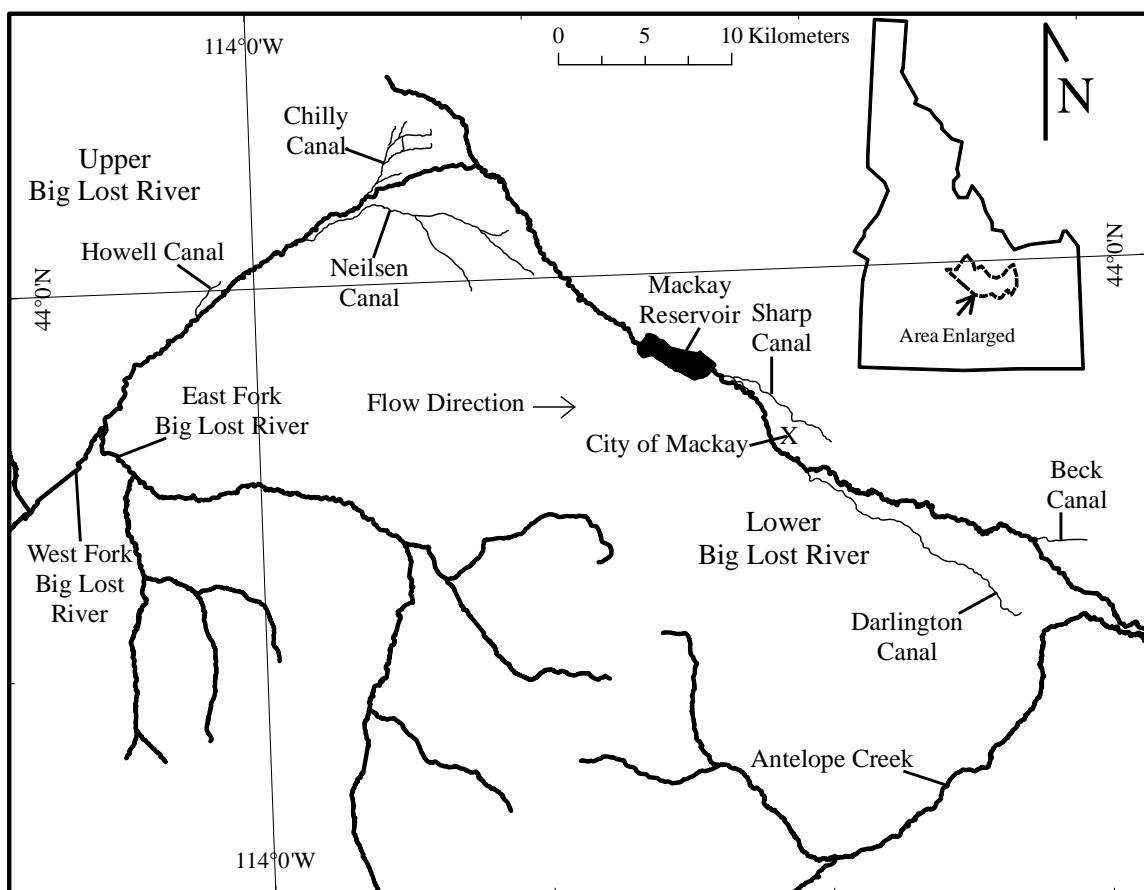


Figure 1. The upper Big Lost River from the confluence of the East and West Fork Big Lost River to Mackay Reservoir, and the lower Big Lost River from Mackay Dam to the Beck canal. The six canals assessed in 2008 are identified.

Electrofishing

Single-pass electrofishing, using a Smith-Root LR-24 battery-powered backpack electrofisher, was identified as the best method to evaluate the large geographic area (Meador et al. 2003). Sample reaches approximately 100 m long were systematically selected in complex habitat where fish are suspected to congregate (e.g. areas near the head gate, or check structures; Roberts 2004). These complex reaches were sampled every other week over the duration that water was diverted. In the upper Big Lost, six

diversions were assessed. Six diversions were also assessed in the lower Big Lost.

Captured fish were anesthetized using MS-222 (tricaine methanesulfonate), identified to species, and measured for total length to the nearest millimeter. Each captured fish had the adipose fin removed, and then was returned to the Big Lost River in the vicinity of the head gate. Diversions included in this assessment are listed in Table 1.

Objective 2 – Estimating mountain whitefish entrainment by six diversions

Having broadly characterized entrainment among diversions in 2007, in 2008 the objective was to estimate the number of mountain whitefish entrained by a subset of diversions in each population stratum. Six diversions were selected from the 12 assessed in 2007. Three above Mackay Reservoir and three below were selected to represent each stratum of suspected entrainment determined by the first objective (Figure 1).

Each canal was stratified into simple and complex habitat. Complex habitat is as defined above, while simple habitat characterized the remaining length of the canal. Complex habitat reaches that were sampled bi-weekly in 2007 were sampled weekly in 2008.

Random sample reaches approximately 100 m long were selected from simple habitats so estimates could be extrapolated throughout the length of the canal (Carlson and Rahel 2007). Each canal was partitioned into 100 m reaches with the complex habitat (100 m upstream and 100 m downstream) excluded (Figure 2). Potential simple habitat reaches were numbered consecutively throughout the length of the canal, with areas further than 500 m from vehicle access excluded. This resulted in exclusion of 24% of possible sample locations in the Darlington canal, and the exclusion of 1% of possible sample locations in the Sharp canal.

Sample reaches considerably downstream from the head gate (hereafter referred to as the extremity of the canal) were also excluded for both biological and sampling reasons. The biological rationale for excluding the extremities was that for a fish to enter these reaches it had to pass through several upstream reaches where it was prone to capture. Excluding the extremities also facilitated a larger sample size and greater replication within selected reaches. Sample locations were chosen by randomly selecting from the remaining number of simple habitat reaches using a random number generator.

Electrofishing

I used electrofishing to estimate the total number of mountain whitefish entrained by each diversion included in the 2008 assessment. For this project, it was assumed that fish captured in the canal downstream of the diversion were permanently removed from the river population (Roberts 2004; Carlson and Rahel 2007). Estimates of the number of whitefish within a selected canal reach relied on multiple-pass electrofishing removals (Peterson et al. 2004, 2005). In removal studies, three general assumptions include: 1) the population is closed during the course of sampling, 2) the amount of effort expended for each sampling period is equal, and 3) the probability of capture for all fish is equal and does not change between removal passes (Hayes et al. 2007).

To account for the first assumption, passage barriers (hereafter referred to as block-nets) were installed upstream and downstream of sample reaches (Peterson et al. 2005). Downstream block-nets, in conjunction with check structures upstream, were used in complex habitat sample reaches. Where block-nets were utilized, cast iron T-posts were driven into the bed of the canal. Polyethylene, 12.7 mm mesh (Industrial

Netting Part # XB 1132) was stretched the width of the canal and was fixed to the T-posts. Cobbles were used to seal the net against the canal bed. To estimate the largest mesh size that could be used, the diameters of ten mountain whitefish with total lengths between 100 and 120 mm were measured using a caliper.

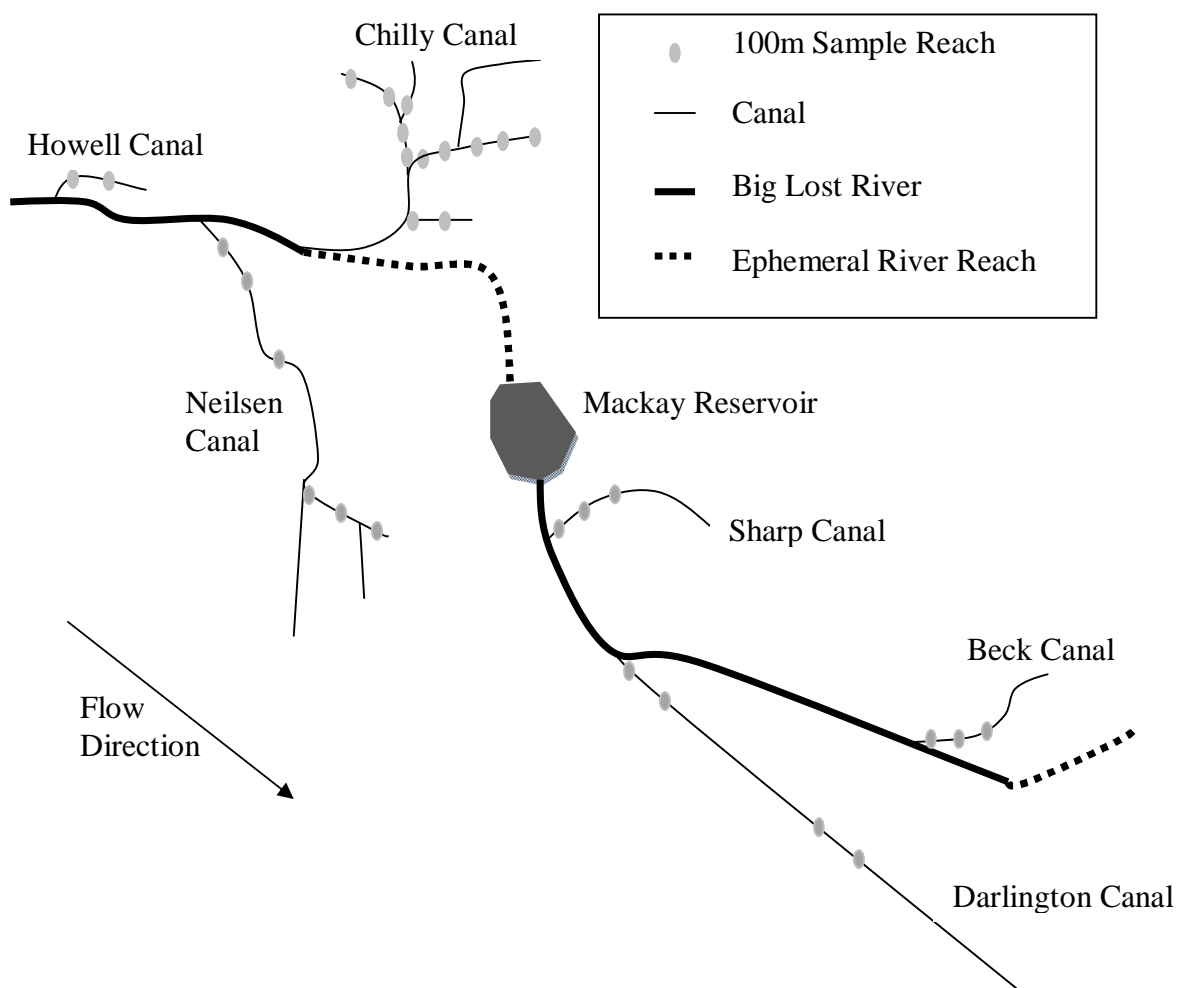


Figure 2. Schematic of the Big Lost River and the six canals where entrainment was estimated in 2008. The Howell diversion is located at the up-river extremity, and the Beck diversion is at the down-river extremity of this assessment. Depletion electrofishing reaches approximately 100 m long are indicated by ovals. Mackay Reservoir and an ephemeral river reach separate the upper and lower Big Lost River reaches.

All measured fish had diameters larger than 12.7 mm. The second assumption was addressed by recording the time, in seconds, that electricity is applied to the water and standardizing the sampling effort. The third assumption was addressed by evaluating capture probabilities over a range of flow, depth, and substrate conditions using a Huggins model (Huggins 1989) in program MARK (Cooch and White 2008).

Capture probability (p) was estimated using the following two methods: First, the rate of depletion between successive electrofishing passes was modeled in program MARK; second, the chemical xylene, applied by the irrigation department, was substituted as a piscicide to estimate capture probability in reaches that were treated with this aquatic herbicide (Bettoli and Maceina 1996).

Capture probabilities were modeled in program MARK using the multiple-pass electrofishing occasions where mountain whitefish were captured. A closed-capture Huggins estimation using two encounter occasions, one group (complex habitat), and one covariate (length), was modeled in program MARK (Cooch and White 2008). Standard models were tested to identify variations in capture probability between electrofishing passes and between fish sizes (Cooch and White 2008). The models were assessed according to Akaike's information criterion (AIC; Burnham and Anderson 1998; Cooch and White 2008). The model with the lowest AIC value was used to estimate the capture probability.

Canals downstream of Mackay Reservoir are treated with the aquatic herbicide xylene to inhibit the growth of aquatic vegetation. Xylene also results in the mortality of fish. In order to estimate capture probability in the field, prior to the xylene treatment, several 100 m reaches were enclosed with block-nets. Double block-nets, spaced 5 m

apart, were installed at the downstream end of each transect to assess the efficiency of the block-nets (Peterson et al. 2004). Multiple-pass electrofishing removals were conducted in both complex and simple habitat strata. Several fish, covering the range of size classes, were retained in live cages at the downstream end within the transect that was most distant from the point where xylene was applied. A second live cage was anchored in the canal approximately 10 m downstream of the transect that was most distant from the point of xylene application. The live cages and the fish inside of them remained in the water column during the treatment to assess the effectiveness of using xylene as a piscicide.

Mountain whitefish movement

Over the course of this project, all mountain whitefish larger than 100 mm had the adipose fin removed so that recaptured fish could be identified. During the 2007 field season, mountain whitefish were released back into the Big Lost River. Returning marked fish to the river helped explain if fish repeatedly become entrained after being returned to the river during salvage efforts.

During 2008, all captured mountain whitefish larger than 100 mm were given a second fin mark using a paper punch, and were returned to the canal to gain an understanding for redistribution within the canal. Multiple sites within each canal were selected, and corresponding fin punches were assigned to each release site. For example, the lower caudal fin was punched, and fish were released at the downstream extremity of a canal. Fish were also marked with an upper caudal fin punch, and released in an upstream reach of the canal within a few hundred meters of the head gate. An anal fin

punch was used for fish released in the middle reaches of the canal. Fin marks and associated release sites were alternated between adjacent canals to minimize error associated with fish potentially moving between canals. Release sites in the middle reaches of the canal concomitantly assessed fish passage over check structures that were included in this assessment as complex habitat. All recaptured fish were recorded and released back into the canal at their original release site. At the end of the irrigation season, all fish encountered were removed from the canal and returned to the Big Lost River.

Temperature

Temperature may play a role in fish movement within canals. Warmer temperatures in the extremities of a canal may become unsuitable during late summer and preclude fish from moving downstream within a canal. This could result in fish migrations back to the river which might bias abundance estimates as fish move into complex habitat sample reaches from un-sampled reaches. To address this question, temperature was recorded at multiple sites in the six canals for the entire irrigation season. Data logger sites were systematically selected to record temperature within 100 m of each head gate, and at seven sites in the extremities of canals. Temperature at three middle sites within longer canals was also monitored. Data was recorded hourly from May 22 to October 12, 2008. Canal temperatures were summarized as seven day average maximum temperatures (MWMT; Dunham et al. 2005).

Entrainment Estimates

Mountain whitefish within a sampled reach were rarely encountered in sufficient numbers to estimate abundance precisely using simple depletion estimators. Therefore, abundances were estimated using three different estimated capture probabilities to bracket true entrainment within a range.

Observed catches were corrected using the mean estimated capture probability, and also using the upper and lower 95% confidence intervals on the mean estimated capture probability. Estimated catch was then averaged at each sample reach over 2-week periods. It was assumed that populations within canal reaches were closed during this 2-week period, and fish did not move between reaches. Abundance was then estimated within the canal over this duration. Assuming the populations within canals were closed for 2-week periods permitted estimating using an average catch which reduced the effect of influential sampling events while preserving seasonal trends. While the closure assumption was most likely violated, this likely had a minimal effect on the population estimates since a similar number of fish moved in and out of the reach over this time span. Two-week in-canal abundance estimates and 95% confidence intervals were calculated to characterize entrainment over that time period. Abundance was estimated for all mountain whitefish larger than 100 mm within each canal. Recaptured fish, identified by fin marks, were removed from these estimates. Annual entrainment estimates were determined for each diversion by summing the in-canal 2-week abundance estimates over the duration that water was diverted (June 1 – November 11, 2008).

The Howell canal lacked any check structures or a head gate so contains only one habitat strata (simple). Abundance estimates within the Howell canal are determined as a simple random sample (Schaeffer et al. 1990). Abundance estimates within the other five canals were determined as a stratified (simple and complex habitat) random sample (Schaeffer et al. 1990).

Mean canal densities for both strata (\bar{y}_{st}) were calculated by summing the products of strata density (\bar{y}_i), and the proportion each stratum made up of the entire canal (W_i) using,

$$\bar{y}_{st} = \sum_{i=1} W_i \bar{y}_i, \quad (1)$$

where $W_i = N_i/N$ is the proportion of habitat stratum (i) within the canal. The total number of habitat units available (N) divided by the number of selected units of habitat strata i (N_i) defines the proportion. This parameter weighs each stratum respectively.

Variance of the mean strata density is given by,

$$\hat{V}(\bar{y}_{st}) = \frac{1}{N^2} \sum_i N_i (N_i - n_i) \frac{s_i^2}{n_i}, \quad (2)$$

where n_i is the total number of habitat units of strata i that were sampled, and s_i is the variance within each habitat stratum respectively. Total estimated abundance ($N\bar{y}_{st}$) was determined by the product of the mean strata density (\bar{y}_{st}), and the total number of possible sample units within the canal (N),

$$N\bar{y}_{st} = \sum_{i=1} N_i \bar{y}_i. \quad (3)$$

Variance for total canal abundance is calculated using,

$$\hat{V}(N\bar{y}_{st}) = N^2 \hat{V}(\bar{y}_{st}). \quad (4)$$

Two-week entrainment estimates and variances are summed over the duration that water was diverted (June 1 – November 11, 2008) for each canal to estimate annual entrainment for each diversion. Annual entrainments are summed to estimate the total annual number of mountain whitefish entrained by the six canals assessed in 2008.

Objective 3 – Physical factors contributing to increased entrainment

Physical factors contribute to increased entrainment, and describe variations in entrainment among diversions (Spindler 1955). By evaluating the physical characteristics of the diversions where entrainment was estimated, predictors of high entrainment among diversions were identified. Identifying predictors of high entrainment will assist in prioritizing further conservation efforts when considering diversions not included in this assessment.

Discharge into canals from the river fluctuates daily in response to river stage and irrigation demand. Discharge was monitored in 2008 in the subset of canals where entrainment was estimated, to validate discharges reported by IDWR, Water District #34 (IDWR 2009), so correlations between discharge and entrainment could be assessed. Simple linear regression was used to assess the relationship between the annual stream volume diverted and the number of fish entrained.

Discharge

Remote water level logger sites were selected within 100 m of the head gate where the canal bed and flows were determined to be uniform throughout the cross section (Harrelson et al. 1994). Water level loggers (HOBO® U20) were anchored

within the selected sites to record changes in fluid pressure and temperature. Barometric pressure was recorded remotely both on the upper and lower Big Lost using HOBO™ PRESSURE remote pressure loggers (minimum distance 11 m, maximum distance 13.5 km). Barometric pressure was used to convert fluid pressure to a water depth.

Discharges were obtained in the canals using a Marsh-McBirney model 2000 portable flow meter (Harrelson et al. 1994). Discharges were measured with the flow meter over the range of potential discharges to develop a reliable rating curve. Rating curves were determined to be reliable if the estimated discharge differed by less than 10% from the discharges measured using the Marsh-McBirney flow meter. Water depths recorded by the water level loggers (x-axis), and the log of measured discharges (y-axis) were plotted and fitted with a power trend-line. The equation of the power relationship was used to convert water depth to volumetric discharge in cubic meters per second (m^3/s).

Discharge for the river was obtained from the United States Geological Survey (USGS) gage #13120500 in the upper Big Lost, and USGS gage #13127000 downstream of Mackay Dam (<http://waterdata.usgs.gov/nwis/rt>). Diversion discharges (Q_D) were divided by the river discharges (Q_R) to determine the daily proportion of the Big Lost River diverted by each head gate,

$$\textit{Proportion Diverted, \%} = (Q_D / Q_R) * 100, \quad (5)$$

where Q_R was estimated by subtracting the sum of all reported diversion discharges of all diversions upstream (IDWR 2008) from the nearest USGS stream-flow gage (Q_{USGS} ; mean daily discharge (m^3/s); <http://waterdata.usgs.gov/nwis/rt>),

$$Q_R = Q_{USGS} - \left(\sum_{i=0}^n Q_{D_i} \right). \quad (6)$$

The daily cumulative proportion of the river diverted was then calculated by summing the proportions diverted and dividing by the USGS stream-flow. This illustrated how much available habitat remained for mountain whitefish after the water was distributed to irrigators. Diverting high proportions of the available river has previously been identified as a predictor for increased entrainment (Spindler 1955).

Objective 4 – Population effect of entrainment above Mackay Reservoir

By combining physical predictors of entrainment, my entrainment estimates, and the most current estimates of mountain whitefish abundance within the river (Garren et al. 2009), the potential impact of entrainment can be estimated at the population scale.

Total catch in 2007 and 2008 was assessed using chi-squared analysis to characterize the differences in entrainment among years and among canals, over the course of this research. The Chilly and the Neilsen were the only canals where mountain whitefish were captured at the same sample reach, and in the same week, during both years of this project. These two canals were also the highest entraining canals in the basin over the duration of this project. Only complex habitat reaches sampled during both 2007 and 2008 were selected for this comparison.

H_0 : The proportion of mountain whitefish captured is equal among years.

H_A : The proportion of mountain whitefish captured in canals is not equal among years.

A contingency table was used to calculate the chi-square value (χ^2 ; $\alpha = 0.05$; Zar 1999).

I then developed a conceptual, pre-breeding census model, to illustrate the birth-pulse life cycle of mountain whitefish in the upper Big Lost River (Figure 3; Caswell 2001). The demographic parameters illustrated in this model were incorporated into a

stage-structured matrix population model. Perturbation analysis of the model theoretically illustrated how entrainment reduced survival to adulthood of juvenile mountain whitefish (Caswell 2001). The population in the upper Big Lost is modeled because the length-at-age of mountain whitefish readily conform to a stage-structured model; where age-0 mountain whitefish in the upper Big Lost are generally < 100 mm, age-1 fish are 100 – 199 mm, age-2 fish are 200 – 299 mm, and generally all mountain whitefish > 300 mm are age-3 or older.

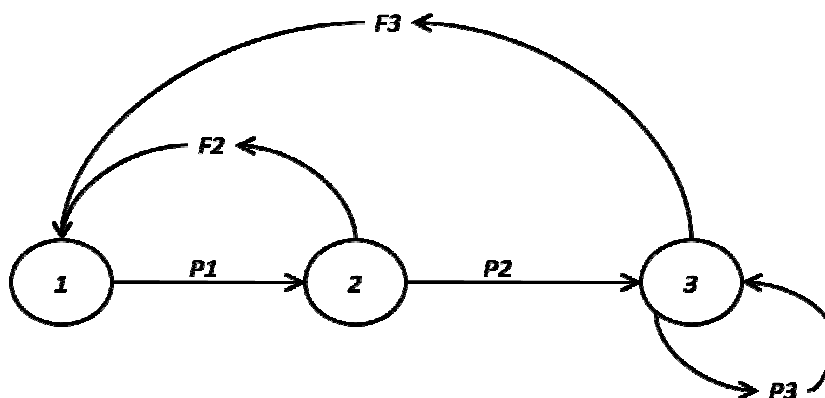


Figure 3. A conceptual, pre-breeding census model was used to illustrate the birth-pulse life cycle of mountain whitefish. The demographic parameters identified here are incorporated into a stage-structured population matrix model. Stages 1 and 2 correspond with ages of mountain whitefish. Stage 3 represents all fish age-3 and older. Survival from stage 1 to stage 2 is represented by $P1$. Survival from stage 2 to stage 3 is represented by $P2$. Survival beyond stage 3 is represented by $P3$. Fertilities and survival from age-0 to age-1 are incorporated in $F2$ and $F3$. Understanding the life cycle of mountain whitefish helped describe the effects of entrainment on the population.

In the conceptual model, life stages are represented in the circles (1, 2, 3), and transitions between life stages are represented by arrows ($P1$, $P2$, $P3$, $F2$, $F3$). Stage 0 are eggs. The transition from stage 0 to stage 1 is represented by $P0$, and is included in this model, but is incorporated into the calculation of $F2$ and $F3$ (see below), and so is

accounted for, but not illustrated in the conceptual model. Stage 1 and 2 represent age-1 and age-2 fish, respectively. The third stage represents all fish that live to age-3 and beyond.

A matrix population model incorporates values for survival (P) and fecundity (m , eggs-per-female) to theoretically illustrate the current state of the population. Values for survival and fecundity are either estimated from the data or were obtained from related literature because no local data exists. Bouwes and Luecke (1997) estimated survival from egg to fry ($P0 = 0.01$) for a broadcast spawning Bonneville cisco (*Prosopium gemmifer*). Survival from age-1 to age-2 ($P1$) mountain whitefish is not reported in the literature. To identify the theoretical range of possible survivals for $P1$, perturbation analysis was conducted by using a range of values for $P1$ (0.01 – 0.06). Survival from age-2 to age-3 ($P2 = 0.21$) was estimated from my 2007 observations in the upper Big Lost River using Robson and Chapman's maximum likelihood estimate of survival (Miranda and Bettoli 2007),

$$S = \frac{T}{N+T-1}, \quad (7)$$

where N is the total number of mountain whitefish captured and T is derived from the distribution of ages,

$$T = \sum(xN_x). \quad (8)$$

Survival for mountain whitefish to age-3 and beyond (>300 mm; $P3 = 0.33$) was obtained from Thompson and Davies (1976). Mountain whitefish in the Big Lost River are not sexually mature until age-2 (IDFG 2007). Fecundity (m) was calculated for each

millimeter increase in size for mountain whitefish between 200 and 400 mm using the relationship described by Meyer et al. (2009),

$$m = 0.000008 \cdot TL^{3.497}, \quad (9)$$

where TL is total length in millimeters. Fecundity was then averaged from 200 – 299 mm ($m_2 = 2,043$), and from 300 – 399 mm ($m_3 = 6,461$). The average fecundity for each reproducing age-class (ages 2 and 3) was multiplied by a sex ratio (0.5) and the survival for P_0 (0.01) to estimate fertility (number of offspring per spawning pair), which is represented in the model as F_2 (10.22) and F_3 (32.31). The demographic parameters for age-3 fish were applied to all fish that survive beyond age-3. A stage-structured matrix model was used to test the model (Caswell 2001). The matrix model (Equation 10) reflects the pre-breeding census, birth-pulse characteristics illustrated by the conceptual model.

$$A = \begin{pmatrix} 0 & F_1 & F_2 \\ P_1 & 0 & 0 \\ 0 & P_2 & P_3 \end{pmatrix} \quad (10)$$

By incorporating the demographic parameters into equation 10 (Equation 11), it is possible to estimate the current theoretical stable-age-distribution, and the population-growth-rate.

$$A = \begin{pmatrix} 0 & 10.22 & 32.31 \\ 0.01 & 0 & 0 \\ 0 & 0.21 & 0.33 \end{pmatrix} \quad (11)$$

Perturbation analysis is a method where demographic parameters are adjusted and changes in the stable-age-distribution and population-growth-rates are observed (Caswell 2001). It was assumed that screening will increase survival to adulthood. If the survivals of P_1 , P_2 , and P_3 are increased in the matrix model, theoretical population benefits are

illustrated by the changes in the estimated stable-age-distribution, and the population-growth-rate.

An elasticity matrix was also constructed using the current population demographic parameters (Caswell 2001). An elasticity matrix scales the effect of relative changes in demographic parameters to 1.0, and illustrates what proportion each demographic parameter contributes to the growth of the population (Caswell 2001).

This population model assumes that mortality and fecundity in this population are density independent and that the environment is constant (Caswell 2001). Mortality and fecundity of mountain whitefish in the Big Lost River are likely density independent due to the extremely low abundances. It is more difficult to meet the assumption of a constant environment. Even if this assumption is not met, the following results are indicative of the population response to screening.

RESULTS

Objective 1 – A basin-wide synopsis of diversions

The a priori stratification of diversions (Table 1) was not fully substantiated by our electrofishing synopsis in 2007. Most diversions were appropriately characterized, but entrainment from the lower Big Lost River was lower than expected when compared to the pilot study or other preliminary data (Table 2). As a result, only the Chilly and Neilsen diversions entrained high numbers of fish during 2007, while low entrainment was observed in all other diversions assessed that year.

The disparity between observations in 2007 and preliminary data is attributed to variations in year-class strength and water management associated with the higher water year in 2006 (Figures 5 and 6).

Table 2. Summary of synoptic electrofishing efforts from June 2 to November 20, 2007. All recaptures were removed. Synoptic methods consisted of single-pass electrofishing in conjunction with block-nets. Effort was concentrated in complex habitat reaches associated with head gates or check structures.

Diversion	MWF >100mm	Total MWF	Effort (h)	Combined Length of Sampled Reaches (m)
Howell	0	1	41.20	172
Kent	0	0	6.83	270
Bartlett/Bitton	0	0	2.48	121
Bradshaw-Upper	0	0	16.06	375
Neilsen	232	1522	248.28	488
Chilly	189	692	641.50	1462
Sharp	5	6	50.53	244
Swauger	9	9	86.52	173
Darlington	3	3	219.71	636
Burnett	1	1	17.97	285
Beck	3	17	357.68	382
3-in-1	1	2	24.18	89

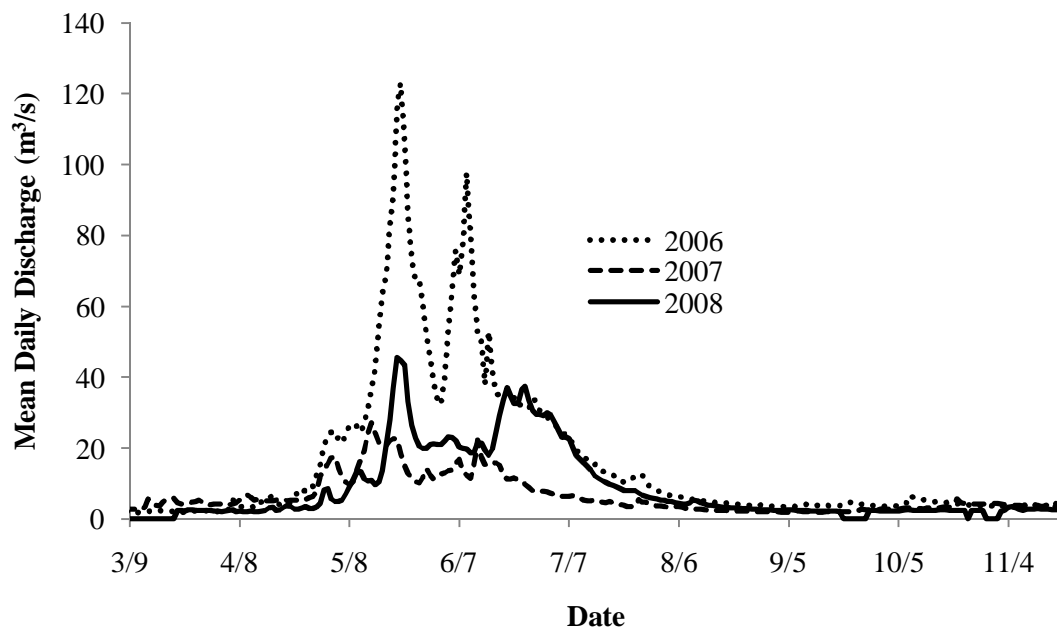


Figure 4. Mean daily discharge (m^3/s) for three years in the upper Big Lost River obtained from USGS gage #13120500.

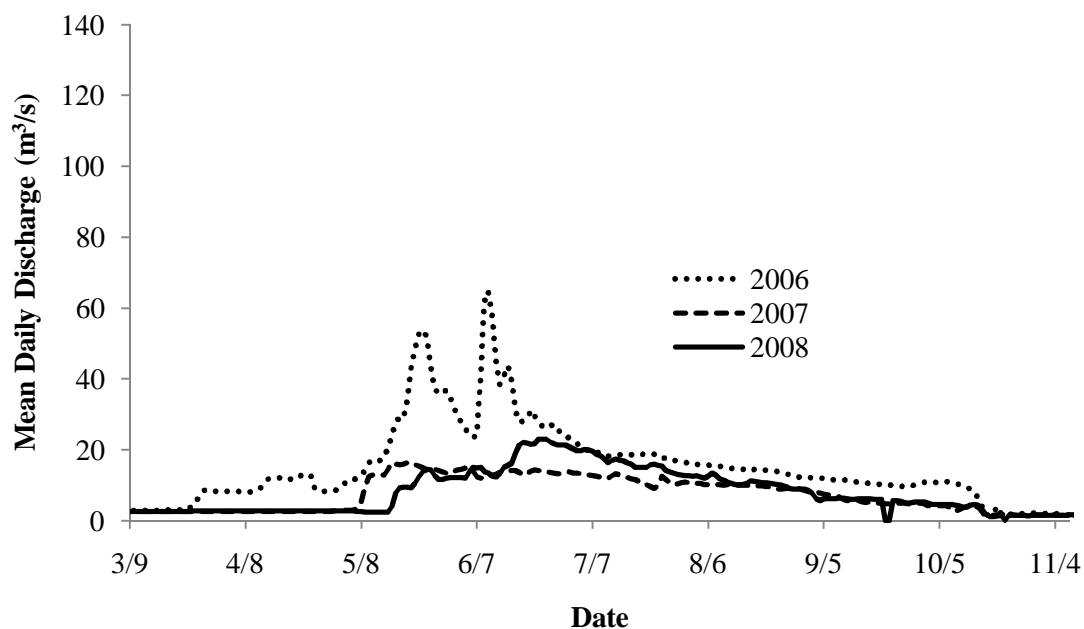


Figure 5. Mean daily discharge (m^3/s) for three years in the lower Big Lost River downstream from Mackay Dam obtained from USGS gage #13127000.

Objective 2 – Estimating mountain whitefish
entrainment by six diversions

A closed-capture Huggins model in program MARK failed to estimate electrofishing capture probability in simple habitat due to the low number of mountain whitefish encountered in this stratum ($n = 11$). Based on the low number of fish captured in all depletion estimates within this stratum, I assumed that capture probability within this stratum was at least equal to the estimated capture probability for complex habitats.

Capture probability for sampling in the complex stratum was modeled using the same Huggins model in program MARK. This model estimated capture probability based on multiple-pass depletion electrofishing surveys in 2008 where fish were captured in at least two passes ($n = 61$). The small sample size ($n = 61$) likely reduced the effectiveness of a multiple model selection process. The best model did not include variation in capture probability, fish lengths, or between electrofishing passes. As a result, capture probability was only estimated for complex strata and where all parameters and covariates are constant. The estimated capture probability for complex strata is used to correct observed catch in both complex and simple strata.

The estimated capture probability was 0.86, with a 95% confidence interval 0.69 – 0.99. Because inconsistent captures of mountain whitefish likely resulted in low statistical power, canal populations were estimated using the lower 95% confidence limit ($p = 0.69$), the mean estimate ($p = 0.86$), and a maximum capture probability, where the catch represents the actual number of fish present ($p = 1.0$). These three estimates bracket the true capture probability because most of the habitat in canals is simple and should have a higher capture probability. Estimates using the lower capture probability

will generate a higher population estimate. Estimates using the highest capture probability simply expand the number of fish captured over all reaches within a canal. The corrected estimates illustrate how the variability in capture probability affects the abundance estimates.

Estimating capture probability (p) using xylene as a piscicide was not successful because no mountain whitefish larger than 100 mm were encountered following the treatments or during our pre-treatment depletions. Complete mortality resulted in all fish within the treated reaches according to the complete mortality observed in cages both within and beyond the sampled transects. At the downstream block-net, fish were observed attempting to avoid the xylene cloud by swimming downstream. No fish passed the block-nets during my observation of this test, and no postmortem fish larger than 100 mm were observed between the double block-nets following the treatment.

Mountain whitefish movement

In 2007, 1,336 adipose fin-clipped mountain whitefish were salvaged from canals and released in the Big Lost River. Eleven of these fish were recaptured within canals (0.82%, $n = 1,336$). This indicates that once a fish has been salvaged from a canal and returned to the river, it is unlikely to be entrained a second time.

In 2008, 59 mountain whitefish were marked and released back into the Chilly canal. Seventeen of these fish were recaptured. Recaptures did not illustrate seasonal or annual trends. Six fish moved very little and were recaptured 565 m or less from their release site ($\bar{x} = 185$; 10 – 565 m). Six fish moved upstream greater than 1000 m ($\bar{x} = 1,291$; 1,245 – 1,360 m). Five fish moved downstream greater than 1000 m

(\bar{x} = 1,512; 1,030 – 2,216 m). Six of the recaptured mountain whitefish in the Chilly canal bypassed check structures on upstream migrations, indicating these structures do not totally block passage.

Also in 2008, ten mountain whitefish were marked and released back into the Neilsen canal. One fish was recaptured 30 m downstream from where it was released 63 days prior. Two mountain whitefish were also marked and released in the Beck canal. One of these was recaptured 200 m upstream from where it was released 13 days prior.

Temperature

During the 2008 irrigation season, canal temperatures illustrated little longitudinal variation. The Neilsen canal is the longest canal where temperature was monitored in 2008. Temperature was recorded at the head gate, in a middle reach (7.29 km downstream), and at the extremity (11.66 km downstream; Figure 6).

In the Neilsen canal, temperature was monitored over greater distances than in any other canal included in this assessment (Table 3). The upper tolerance limit for mountain whitefish was estimated to be 23.2 C° (Eaton et al. 1995). Maximum incipient lethal temperatures for mountain whitefish are not reported in the literature; however, 23.2 C° is near the maximum lethal temperatures for other salmonids indigenous to this region (Bear et al. 2007). Maximum temperatures were observed during middle July (Figure 6). All other canals where temperature was assessed, universally illustrated less variation in average minimum and maximum daily temperatures (Table 3).

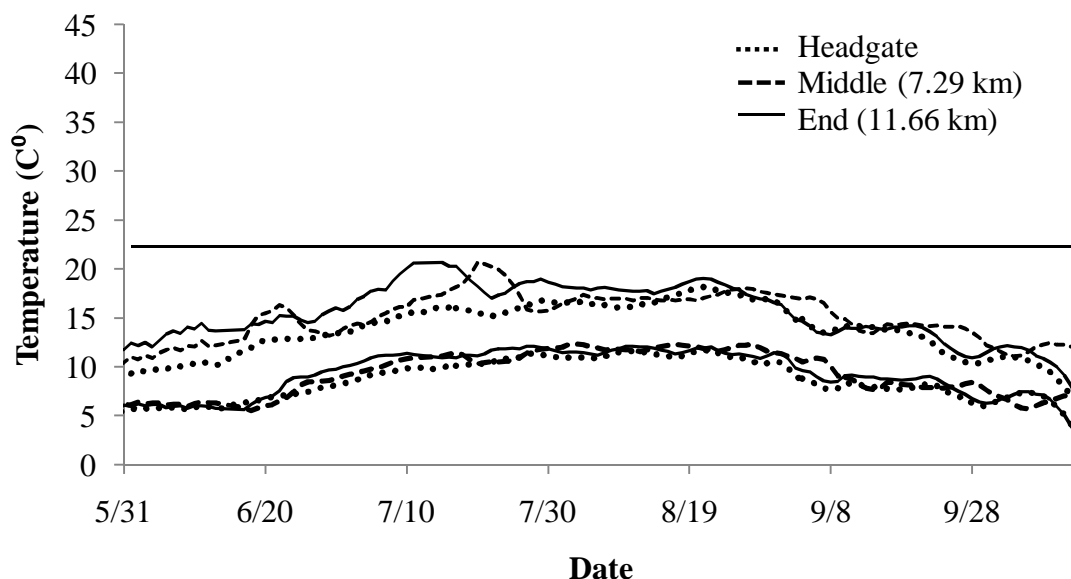


Figure 6. Seven day maximum and minimum average temperatures (C°) recorded at three sites in the Neilsen canal from May 22 to October 12, 2008. Minor longitudinal temperature variations were observed within canals during the second season of this project. Critical maximum temperatures (≥ 23 C°; solid line) were never observed during the 2008 irrigation season. The extremity canal reaches are dewatered several times during the season. These data were removed; however, they identify how canal conditions can be unstable and unsuitable for fish within canals.

Entrainment Estimates

The majority of fish encountered within canals were captured within complex habitat strata. Based on our sampling, complex habitats have higher densities of mountain whitefish than simple habitats. Although lower densities of mountain whitefish were encountered in simple habitats, the majority of canal habitat is characterized as simple habitat. As a result, the estimated abundance of mountain whitefish within a canal is driven by the proportion of simple strata to complex strata due to the large number of simple habitat reaches within each canal.

Two-week abundance estimates were determined for each canal (Figures 7 and 8). Entrainment peaks seasonally during late summer to early winter. Entrainment was

Table 3. Temperature (C°) was recorded using temperature loggers near the head gates, middle reaches, or the extremities of the canal.

Data Logger Site	Mean	Median	Standard Deviation	Maximum	Minimum	Distance (km)	Duration
Howell Head							
Gate	11.05	11.04	3.42	17.86	3.89	0.01	5/22 - 8/20
Extremity	11.57	11.70	3.46	19.20	2.54	2.66	5/22 - 8/20
Neilson Head							
Gate	10.91	10.94	3.39	19.00	0.12	0.02	5/22 - 10/12
Middle	11.39	11.80	3.52	19.20	0.10	7.29	5/22 - 10/12
Extremity	11.79	11.90	3.69	22.50	0.30	11.66	5/22 - 10/12
Sharp Head							
Gate	14.09	14.13	2.46	18.71	9.57	0.18	5/29 - 10/1
Extremity	13.87	13.60	3.20	22.80	6.90	4.09	5/29 - 10/1
Darlington							
Head Gate	13.31	13.75	3.31	24.64	3.05	0.14	5/24 - 10/17
Extremity	13.54	13.80	4.15	22.70	0.01	6.36	5/24 - 10/17
Beck Head							
Gate	14.32	14.33	3.51	21.86	2.84	0.04	5/31-10/12
Extremity	14.04	14.00	3.56	24.10	2.40	0.70	5/31-10/12

lowest during middle summer. Seasonal trends reflect variations in water management and mountain whitefish biology.

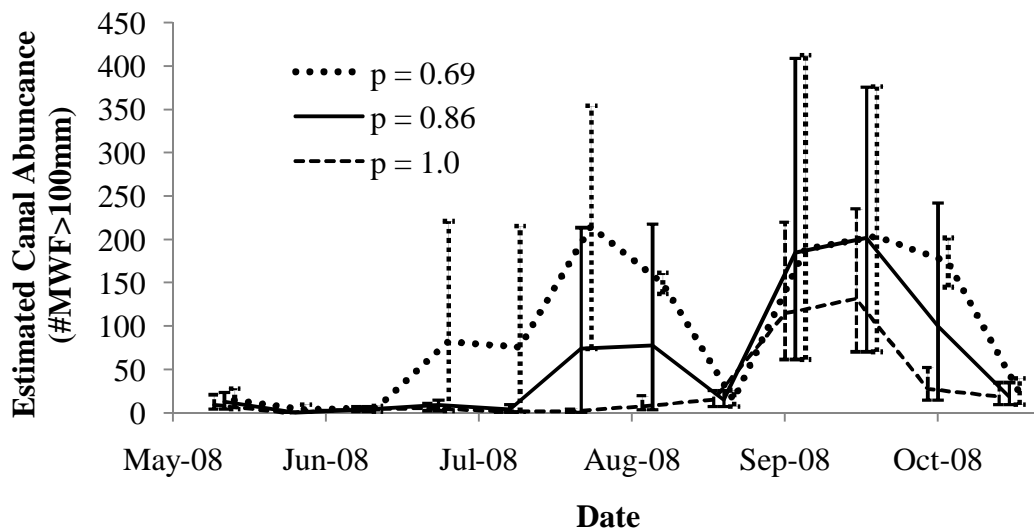


Figure 7. Two-week entrainment estimates and 95% confidence intervals for the Neilsen diversion in 2008. Estimates were calculated for 2-week periods in 2008 at three capture probabilities (p) for mountain whitefish (MWF) larger than 100 millimeters.

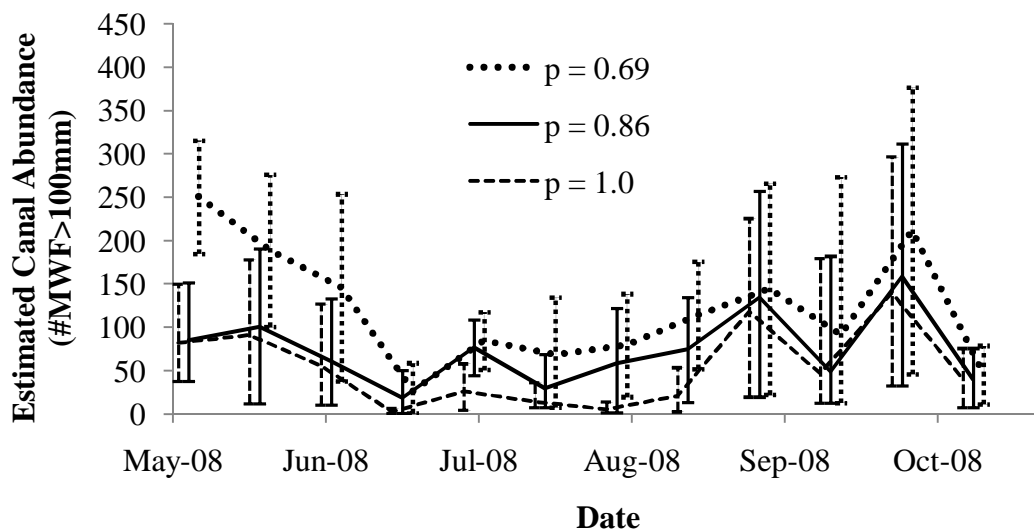


Figure 8. Two-week entrainment estimates and 95% confidence intervals for the Chilly diversion in 2008. Estimates were calculated for 2-week periods in 2008 at three capture probabilities (p) for mountain whitefish (MWF) larger than 100 millimeters.

The total number of mountain whitefish estimated to be entrained by the six canals during 2008 varies substantially (Table 4). The Neilsen and Chilly diversions account for greater than 95% of the total number of mountain whitefish entrained (Table 4). Almost all of the entrained fish occurred in the upper Big Lost (Howell, Neilsen, and Chilly; Table 4). Very few fish were captured within canals in the lower Big Lost (Sharp, Darlington, and Beck; Table 4). Confidence intervals for the entrainment estimates are wide after accounting for variance in captures within each stratum, capture probabilities, and expansions to un-sampled habitat.

Table 4. Estimated annual entrainment and 95% confidence intervals for all mountain whitefish larger than 100 mm in six canals on the Big Lost River. Entrainment was estimated over a range of capture probabilities to bracket the value of true abundance. The sum of annual entrainment is the estimated number of fish entrained by these six diversions during 2008.

Diversion	(<i>p</i>=1.0)	95% CI	(<i>p</i>=0.86)	95% CI	(<i>p</i>=0.69)	95% CI
Howell	33	20-45	59	3-121	124	11-236
Neilsen	337	183-490	701	325-1077	1151	775-1526
Chilly	642	367-917	886	592-1181	1450	1112-1788
Sharp	3	1-8	75	1-197	159	31-286
Darlington	0	0	183	0-524	336	0-847
Beck	5	2-12	31	2-93	79	2-181
sum =	1018		1935		3297	

Objective 3 – Physical factors contributing to increased entrainment

Discharge

To assess the relationship between discharge and mountain whitefish entrainment, the annual sum of daily-mean canal discharge, as reported by IDWR Water District #34

in their annual distribution report (IDWR 2009), was extrapolated to total daily volume diverted (acre feet), and was regressed against the entrainment estimates (Table 4).

Simple linear regression identified a significant relationship between these two predictors (Figure 9).

Greater volumes of water are diverted during high spring flows, but the large volume within the river during this time of year results in a smaller proportion of the available flow diverted (Figure 10). During late summer and early fall, lesser volumes of water are diverted, but due to low stream-flow during this time of year, a high proportion of the stream is diverted (Figure 11). This condition coincides with the mountain whitefish spawning season and may result in increased entrainment.

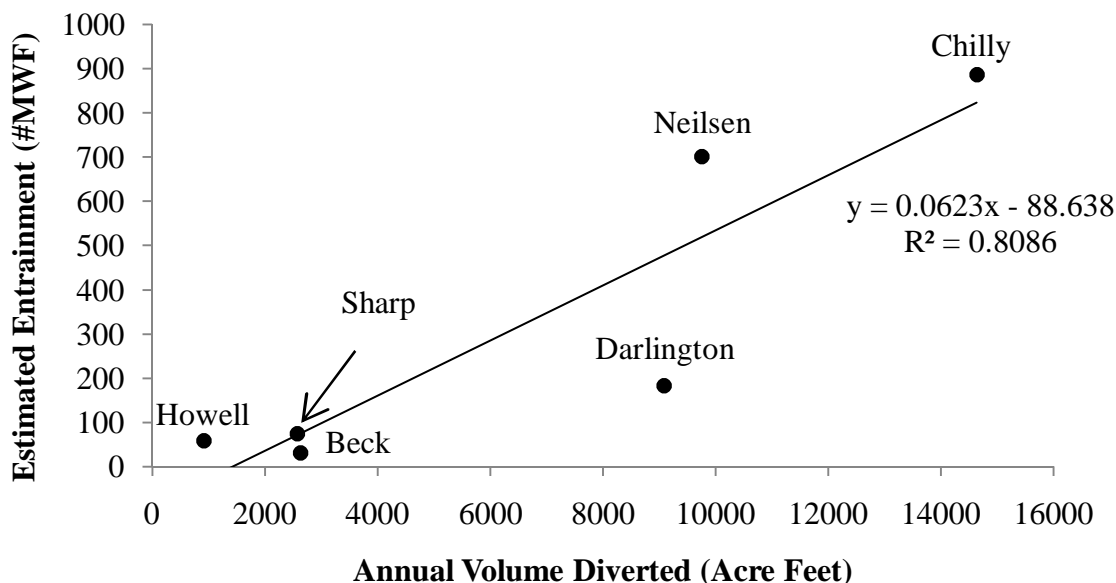


Figure 9. The annual estimated number of mountain whitefish ($p = 0.86$) entrained by six diversions was regressed against the total volume diverted over the irrigation season. The linear trend line illustrates a positive correlation. This identifies greater discharges as a predictor of increased entrainment.

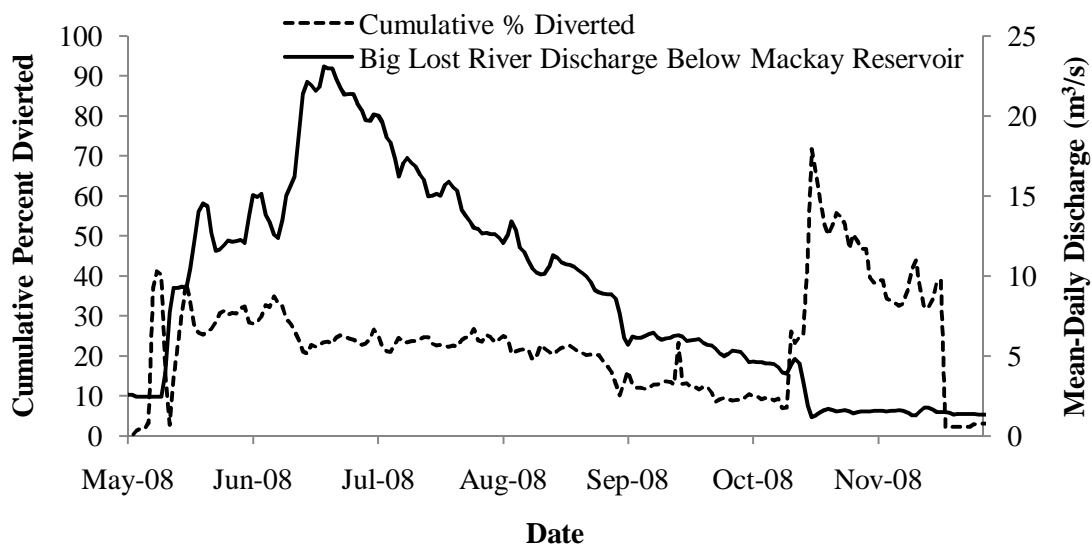


Figure 10. Cumulative percent of the lower Big Lost River diverted in 2008. The cumulative proportion was determined by summing all diverted flow and dividing by the mean-daily discharge (m^3/s) at USGS gage #13127000.

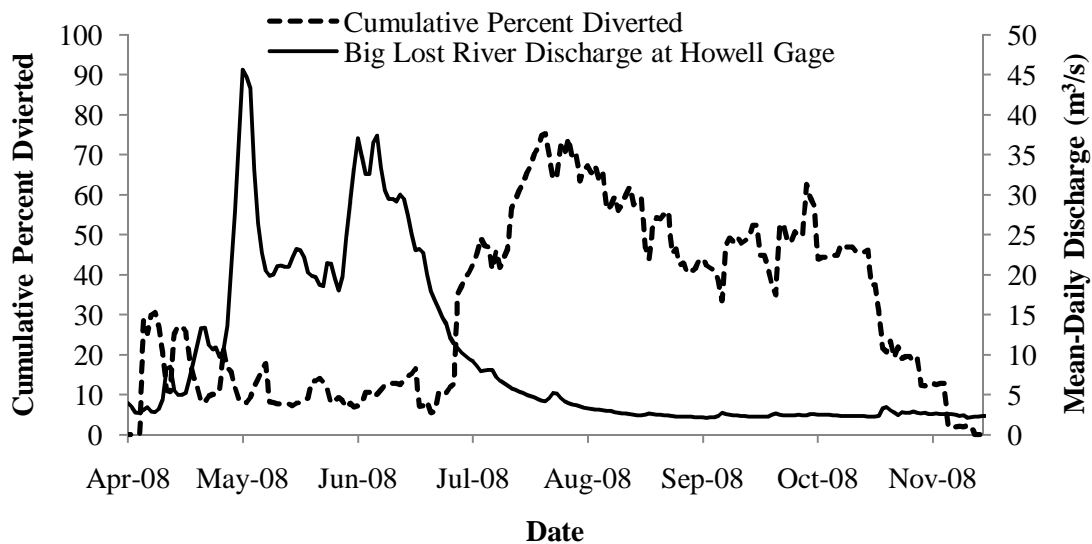


Figure 11. Cumulative percent of the upper Big Lost River diverted in 2008. The cumulative proportion was determined by summing all diverted flow and dividing by the mean-daily discharge (m^3/s) at USGS gage #13120500.

Objective 4 – Population effect of entrainment above Mackay Reservoir

My assessment of the effect that entrainment has on the mountain whitefish population was limited to the diversions in the upper Big Lost River. Low catches, in combination with low mountain whitefish population estimates in the lower Big Lost River, limit any inferences in this study reach.

Significant differences ($P < 0.05$) in entrainment were observed among years, and among diversions (Table 5). I rejected my null hypothesis and concluded there is a significant difference in entrainment among years.

In 2007, there were significantly more fish captured than in 2008 (Table 5). Also in 2007 there were twice as many fish captured in the Neilsen than in the Chilly canal (Table 5). In 2008, the opposite pattern was observed, where twice as many fish were caught in the Chilly than in the Neilsen canal (Table 5). This identifies that entrainment differed among years as well as among diversions.

Table 5. Chi-square contingency table where the proportions of observed fish in the Chilly and Neilsen canals are compared with the expected number of fish ($\alpha = 0.05$) to calculate the χ^2 value. This illustrates a significant variation in entrainment among years.

	Observed			Expected			χ^2		
Year	Chilly	Neilsen	Sum	Chilly	Neilsen	Sum	Chilly	Neilsen	Sum
2007	117	221	338	133.35	204.65	338	2.01	1.31	3.31
2008	42	23	65	25.65	39.35	65	10.43	6.80	17.23
Sum =	159	244	403	159	244	403	χ^2 value =		20.54

Perturbation of the population matrix model was conducted by increasing the survival of mountain whitefish at each age-class, and observing the changes in stable-

age-distribution and population-growth-rate. Lambda (λ) represents the population-growth-rate. When lambda equals 1.0, the population-growth-rate is stable. Lambda greater than 1.0 indicates population growth, and lambda less than 1.0 indicates that population abundance is in decline. Perturbation analysis of survival ($P1$, $P2$, and $P3$) revealed that much greater increases in age-2 to age-3 survival ($P2$), and survival of older age classes ($P3$) were required to increase the population-growth-rate above 1.0. Lesser increases in the survival of $P1$ resulted in an increase of the population-growth-rate above 1.0. Perturbation analysis suggested increasing survival from age-1 to age-2 ($P1$) could result in a positive population response (Table 6).

This population can theoretically be stabilized ($\lambda = 1.0$) if survival of $P1$ is 0.05. Survival of $P0$ and fertilities (F_i) could also be manipulated in the perturbation analysis of this model. Because these demographic parameters will not be altered if entrainment is reduced, we did not manipulate those values in our perturbation analysis. There will be no further discussion of the effect that alteration of these parameters might have on population growth.

Table 6. Results for a stage-structured population matrix model. The survival of mountain whitefish from age-1 to age-2 ($P1$) is altered to illustrate how the population-growth-rate (λ) will theoretically increase when entrainment is decreased. If lambda (λ) > 1.0 , then the population abundance will increase.

Parameter	$P1$ Survival	Population-Growth-Rate (λ)
$P1$	0.01	0.59
$P1$	0.02	0.74
$P1$	0.03	0.84
$P1$	0.04	0.93
$P1$	0.05	1.01
$P1$	0.06	1.08

Due to the current low population estimates, I made the assumption that survival to adulthood was low enough to cause a lambda below 1.0 ($PI = 0.03$; $\lambda = 0.84$). The perturbation analysis illustrated the theoretical changes in stable-age-distribution that might result from screening diversions or when population growth is stabilized ($PI = 0.05$; $\lambda = 1.01$). The current stable-age-distribution (95.2% age-1, 3.4% age-2, and 1.4% age-3) suggests a high proportion of age-1 fish make up the entire population of mountain whitefish. Increasing survival to adulthood causes the stable-age-distribution (93.9% age-1, 4.7% age-2, and 1.4% age-3) to shift a proportion of the age-1 fish to age-2. Theoretically, this illustrates that if entrainment reduced survival to adulthood (PI) by a couple percent, then population growth would be destabilized as lambda dropped below 1.0. Intuitively, if screening increases the current survival of PI , then theoretically the population will be stabilized.

The elasticity matrix for the stage-structured population matrix reinforced the results of the perturbation analysis (Table 7). All values in the elasticity matrix sum to 1.0. The proportions in the matrix represent the theoretical proportional influence on population growth. Survival of juvenile mountain whitefish to adulthood (PI) has the greatest influence on the state of this population.

Table 7. Elasticity matrix for the stage-structured population matrix model. The elasticity matrix illustrates the proportional contribution of each demographic parameter on population growth. All proportions within the elasticity matrix sum to 1.0. This identifies survival of PI mountain whitefish to have the greatest impact on the population-growth-rate.

0	0.12	0.20
0.32	0	0
0	0.20	0.16

DISCUSSION

The scale of entrainment assessments has received much attention in recent studies (Post et al. 2006; Carlson and Rahel 2007; Gale et al. 2008; Roberts and Rahel 2008). The scale of an assessment can help to differentiate between community and population effects, and can identify entrainment losses as additive or compensatory. Due to the current state of the mountain whitefish population in the Big Lost River (IDFG 2007), our results represent additive mortality, as it is assumed that compensatory mortality does not exist for a population well below carrying capacity.

The a priori stratification of diversions proved helpful in assessing the effect of diversions on the mountain whitefish populations. The stratification of diversions as high, moderate, and low conformed well to observed entrainment in the upper Big Lost; however, entrainment in the lower Big Lost was not well characterized by this stratification (Table 1; Table 4). Where stratification of potential entrainment relied on data from the 2006 pilot study, the effects of entrainment were over estimated in the lower Big Lost. This was likely attributed to river conditions and water management associated with the higher water year in 2006 (Figure 5). Significantly fewer fish were encountered in the lower Big Lost in 2007 and 2008 than were documented during the pilot study in 2006. Some diversions that were anticipated to entrain substantial numbers of fish diverted less water, or were not operational, in 2007 (IDWR 2007, 2008). Also during 2006, water was diverted over dry ground in order to recharge ground water. As a result, many age-0 and age-1 mountain whitefish were mortally desiccated. Lesser water years in 2007 and 2008 did not allow for ground water recharge using this method.

Large unscreened diversions are likely limiting the population in the lower Big Lost River. One factor limiting the lower Big Lost population that does not affect the upper Big Lost population is the application of the aquatic herbicide xylene. Even in canals where head gate velocities may not prevent fish from moving back to the river, the application of xylene at the head gate results in mortality to all fish within the canal. We did not encounter any mountain whitefish larger than 100 mm in our pre-treatment depletions or during post-treatment assessment. While this did not contribute to our capture probability estimate, it did substantiate our observations of few whitefish within a sampled reach because the herbicide/piscicide provided a census of fish remaining within reaches after our depletion.

Mortality induced by xylene biased my observed catch and resulted in underestimates of mountain whitefish entrainment (Table 4). Therefore, the population effects of diversions in the lower Big Lost were difficult to assess and are therefore still not well understood.

The basin-wide synopsis resulted in an understanding of how entrainment affects mountain whitefish at the community level in the Big Lost River (Meador et al. 2003). By combining the results from two seasons, I acquired a basin-wide understanding of the population effects to the mountain whitefish (Schill and Beland 1995; Carlson and Rahel 2007).

In 2007 and 2008, the diversions assessed in the upper Big Lost caused greater losses to the mountain whitefish population (Table 4). Among the diversions in the upper Big Lost, the Chilly and Neilsen diversions were identified as the largest diversions (IDWR 2009), and they had the greatest impact on the mountain whitefish population in

the upper Big Lost (Table 4). Generally, larger diversions entrain more fish (Spindler 1955; Carlson and Rahel 2007; Gale et al. 2008), and this was substantiated by the relationship between the volumes of water diverted and the number of fish entrained (Figure 9).

The effects of entrainment varied within diversions as well. The 3-in-1 diversion was identified as entraining high numbers of mountain whitefish in 2006, but was not operational in the following two years of this project (IDWR 2007, 2008, 2009). When it is operational, however, the 3-in-1 diversion can function as a terminal diversion where the entire river is diverted into the canal. As illustrated by the Chilly diversion in the upper Big Lost, this confirms our assumption that terminal diversions have a high potential to entrain fish.

The variable effects of entrainment by the Chilly and Neilsen diversions were identified by chi-square analysis (Table 5). The variable effect within these diversions may be attributed to year-class strength or variations in spawning locations (Freeman et al. 2001; Durham and Wilde 2006). Those diversions assessed in reaches where spawning occurs entrained more fish (Clothier 1953; Carlson and Rahel 2007).

Variations among water years may result in relocation of spawning aggregates as the availability of suitable spawning habitat changes (Durham and Wilde 2006). High water years within the Big Lost River, may result in strong year-classes of mountain whitefish, causing increased entrainment (Freeman et al. 2001; Durham and Wilde 2006). Despite more fish being entrained during high water years, we speculate that the population effects of entrainment might be greater during low water years. During lower water years, higher irrigation demands likely result in reduced habitat as larger

proportions of the river are diverted. If poor year-class strength was also caused by low water years (Durham and Wilde 2006), then population effects may be more extreme during low water years or drought conditions.

The effect of each diversion varies (Table 4). The combined effect of all diversions adversely impacts the biotic structure and stability of the mountain whitefish populations in the Big Lost River. Even though smaller canals divert fewer fish on most occasions (Table 4), the summed entrainment of all smaller diversions may have a measurable impact on this sparse population.

Entrainment of mountain whitefish was correlated with flow (Figure 9). Therefore, better estimations of canal discharge will increase accuracy when characterizing potential entrainment of diversions not considered in this assessment. A quantitative assessment of the IDWR distribution report (IDWR 2008, 2009) illustrated high scatter between their data and my flow meter measurements. Also, comparisons of estimated discharge, using remote data loggers, did not substantiate reported discharges measured by the water district. Within IDWR records, the ditch rider logs differed from the annual distribution report (IDWR 2009). As a result, it is difficult to determine exactly how much water is diverted. Given the emerging water-stage technology, sensors should be used to monitor the amount of water diverted. A better understanding of the total amount of water diverted would likely improve the understanding of whitefish entrainment in the Big Lost River.

The second objective was to estimate the number of fish entrained by the six diversions identified in the first season to represent each strata of expected entrainment in both populations. Entrainment of mountain whitefish was difficult to estimate primarily

because of the large number of simple habitat units that contained few fish. The high number of sample events where few fish were captured ($n = 0 - 5$) resulted in high variance (Table 4; Figures 7 and 8). Given the large amounts of simple habitat within canals, it was only possible to sample a small proportion of these habitats. Sampling more of the simple habitat units would reduce the variance in our estimates, but would have substantially increased the cost of our assessment.

Capture probability appeared to be high in simple habitats, but due to the low number of fish encountered in these reaches, it will always be difficult to precisely estimate capture probability within simple habitat. As a result, single-pass electrofishing will allow for sampling a greater proportion of these habitats and may accurately index relative abundance (Kruse et al. 1998) when capture probabilities are high in these reaches. Large-scale assessments may find that intensive sampling of complex habitats is the best synoptic method for identifying those diversions that entrain the most fish, since the majority of fish are captured in these habitats. The accuracy of inferences may be increased when entrainment is estimated over a range of capture probabilities that bracket the true estimate.

A better understanding of mountain whitefish movement within the Big Lost River and the canals would improve entrainment estimates. Less than one percent of previously entrained fish that were returned to the river were recaptured within canals in 2007. This result identified that population benefits can be achieved by salvage efforts at the end of the season when canals are dewatered.

My assessment of mountain whitefish movements within canals revealed little information. Fish were observed moving in both directions within canals during the same

time. Also, when some fish were moving considerable distances within canals, other fish were recorded moving short distances during that same time interval. These results did not identify any seasonal trends of mountain whitefish movement within canals.

Those diversions in operation during mountain whitefish spawning, when movement is suspected to increase, will entrain more fish (Carlson and Rahel 2007). After emerging from the egg, fry and juveniles may be entrained with high flows, thus deleteriously impacting recruitment to adulthood. In the fall, when mountain whitefish are spawning, entrainment may increase because adults are migrating to spawning locations, and juveniles are migrating from rearing locations (Carlson and Rahel 2007).

Temperatures throughout the canals were generally cool. Canal temperatures peaked in the mid-summer (Figure 6) when observed captures were lowest (Figures 7 and 8). Observations of canal temperatures suggest fish movement was not influenced by unsuitable temperatures in un-sampled reaches, as few fish inhabit the canal during the period of high temperature (Figures 7 and 8). Therefore, the entrainment estimates are probably not biased by fish movement within the canal. In the lower Big Lost River fish movement within canals was not understood, but did not influence my estimates. Xylene application within canals removed all fish within canals during the late summer when increased temperatures could have influenced movement.

Modeling suggests entrainment by the Neilsen and Chilly diversions reduced survival to adulthood of juvenile mountain whitefish in the upper Big Lost River by 2-6%. Given the precision of the entrainment estimates, and the estimated demographic parameters within the model, this estimated effect should be cautiously regarded. This is a minimum estimate because entrainment was only considered for mountain whitefish

larger than 100 mm at high estimated capture probabilities. It is likely that many more mountain whitefish are entrained as fry or juveniles and capture probabilities are substantially lower for fish of these sizes.

Model estimates suggest entrainment could be a primary factor contributing to the instability and the low abundance of the mountain whitefish population. Further efforts should concentrate on refining the stage-structured matrix model into a stochastic model that incorporates more precise demographic parameters, better population estimates, and variations in water year.

Conclusions

This project addressed a current management issue intended to describe the impact that entrainment by irrigation diversions is having on the mountain whitefish population on the Big Lost River. It is unlikely entrainment is the sole factor for the decline in the population; however, it was identified that entrainment had a substantial, negative impact on this population. Furthermore, of all the factors potentially contributing to the population decline, the impact resulting from entrainment can be most simply addressed (screening) to benefit the population. If entrainment of age-1 mountain whitefish is minimized, population abundance will likely stabilize or increase (Table 6).

Three physical characteristics and one operational mechanism that contribute to increased entrainment were identified. Entrainment increases with the proportion of water diverted from the river (Figure 7; Figure 10). Similarly, those diversions that are terminal, or divert the entire flow, leave downstream migrating fish no option, but to be entrained. Therefore, this characteristic is recognized as a factor that contributes to

increased entrainment. The location of the diversion in relation to the densest proportion of the population has an effect as illustrated by the disparity between my estimates in the upper and lower Big Lost (Table 4; Schrank and Rahel 2004; Carlson and Rahel 2007).

Entrainment varies among years. Greater volumes of water are diverted during higher water years and more fish are diverted as well. Increased survival of eggs in high water years may contribute to higher entrainment in those years, but might also lead to larger year-classes which results in higher abundances (Freeman et al. 2001; Durham and Wilde 2006). The population effects may be greater during low water years when the population is limited by poor reproduction and greater proportions of the river are diverted.

A few of the diversions could account for the majority of mountain whitefish entrainment. In the upper Big Lost, the Chilly and the Neilsen had the greatest impact on the mountain whitefish population (Table 4). Because of the terminal nature of the Chilly diversion, it has a higher potential to adversely impact the population. All other diversions within this study reach were generally small. Some of these diversions are only operational during high water; however, where diversions are operational during late summer and early fall the potential population effect increases (Figures 7, 8, and 11).

Conservation efforts should be focused on those diversions located near the densest portion of the population and those diversions located where mountain whitefish spawning has been identified.

The river conditions below Mackay Dam are less pristine with limited spawning substrates, the habitat is fragmented by large diversion dams and the flow is more heavily diverted than the upper river. The mountain whitefish population reflects these

conditions. Increasing base flows beyond the 3-in-1 diversion would contribute to the habitat availability for a population already reduced to 25% of its historical distribution (IDFG 2007).

Future assessments should focus on the lower Big Lost so that the mountain whitefish population there will persist, and so then two populations would increase the viability of the entire Big Lost River mountain whitefish population. The population of mountain whitefish in the lower Big Lost is currently limited by multiple factors. Reducing entrainment is one factor that fish and water managers can address to efficiently benefit both populations. The results of this assessment suggest that the upper Big Lost mountain whitefish population will benefit substantially by reducing entrainment at the Neilsen and Chilly diversions. When entrainment in the Big Lost River is minimized, this unique population should persist for future generations.

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