Quantifying the population impacts of Snake River cutthroat loss to irrigation canals for the Gros Ventre River, WY

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Abstract

The Gros Ventre River contains some of the last remaining large, connected, core habitat for fine-spotted morphotype of Yellowstone cutthroat trout, *Oncorhynchus clarkii bouvieri*. The cutthroat trout population in the lower Gros Ventre River may be limited by the effects of multiple irrigation canals. Such a large proportion of the river is diverted, that fish habitat and flow is often completely eliminated near its confluence with the Snake. Such diversions are compounded by the fact that the river reach where irrigation water is diverted also loses a substantial amount of water via natural loss and seepage. Through electrofishing, and detecting tagged fish at fixed stations and bidirectional trap nets in canals during 2007 and 2008, we evaluated the seasonal use of these canals as trout habitat, quantified entrainment, and calculated the population impacts to the Gros Ventre River cutthroat trout population. Entrainment rates increased throughout the summer season, with entrainment of trout peaking in the late summer and fall. Fish entering irrigation canals in the spring and early summer exited the canals, while those that entered the canals in late summer and fall remained in the canals and were lost to the population. Of the fish that entered canals, we detected 38% returning to the river, most after less than a week in the canals. Habitat surveys also indicated canals were relatively poor habitat compared with nearby spring creeks, thus irrigation canals do not provide quality summertime habitat for cutthroat in this basin. Between 0 and 8.6% of tagged fish were entrained depending on where the fish were tagged and the time of year resulting in a potential increase of 6% in annual mortality. Incorporating this increase in mortality into population models indicated that entrainment mortality may decrease potential cutthroat production in the lower Gros Ventre River spawning population, but is unlikely to impact cutthroat trout population basin-wide. Although entrainment mortality is a small part of the entire basin-wide population, it is biased towards the migratory life history component as they attempt to migrate between the Gros Ventre and the Snake River systems.

Introduction

Irrigation canals in the intermountain west are ubiquitous. These canals can influence the quantity and quality of habitat, as well as serve as an important source of mortality. Irrigation canals divert a substantial flow of many tributaries and rivers which may result in reduced habitat volume especially during critical low water periods, warmer waters, reduction in peak flow, and fragmentation of habitat. Loss of fishes to irrigation canals has been historically documented and fish screens have been a potential management solution since the late 1800's (Clothier 1953, 1954). Even so, entrainment of fish of all species and life stages into canals may still be an important source of mortality, in particular migratory components of fish populations may be more vulnerable to entrainment (e.g., Fleming et al. 1987, Schrank and Rahel 2004). In addition to commonly considered anadromous salmon, inland trout that move among multiple habitats may be very vulnerable to entrainment (e.g., Schrank and Rahel 2004, Post et al. 2006, Carlson and Rahel 2007, Gale et al. 2008).

Water leasing and drought plans to help alleviate poor habitat conditions in streams and rivers require a high investment by watershed groups, landowners, conservation groups, and/or management agencies. Technological solutions to entrainment are common and improvements to fish screens are ever-increasing, but installations and maintenance of screens on multiple large diversions are expensive and time consuming. In addition, in some areas the geology (alluvial, dynamic river channels) and land ownership can make fish screens and return channels difficult to install and maintain. Given the potential costs of these management actions, we need to evaluate these costs against population level benefits. Many reports describe the occurrence of thousands of individual fish in irrigation canals, but few examine the broader potential population impact (see Post et al. 2006, Carlson and Rahel 2007). Interestingly, recent basin-wide assessments have found areas with high numbers of entrained fish, but demonstrate relatively small impacts of fish loss to irrigation canals compared with basin-wide population estimates (<1-3%; Post et al. 2006, Carlson and Rahel 2007). We need to develop approaches to quantify mortality and estimate whether this additional entrainment mortality is having population level impacts. In addition, we need a broader understanding of the spatial and temporal patterns of entrainment to evaluate low cost, non-structural solutions to minimize entrainment, such as temporary head gate closures.

Adult trout and their habitat in the Lower Gros Ventre River (lower 19km) may be limited by the effects of irrigation canals; low river flows are exacerbated by natural losses in the river reach where most of the diversion points are located so that river flow (and fish habitat) during many years is often drastically reduced near Highways 191 bridge before it reaches the confluence with the Snake River. This may reduce the quantity and quality of trout habitat in the Gros Ventre River, serve as a barrier to fish movement between the Gros Ventre and the Snake River ecosystems, and be a large source of mortality for trout (e.g., Schrank and Rahel 2004, Gale et al. 2008). Any period of movement can increase encounter with canals and susceptibility to entrainment including, age-0 postemergence dispersal (Northcote 1992), subadult or adult downstream movements from headwater streams to overwintering habitats (Jakober et al. 1998), and movements to other habitats within a river. Given the high rates of water withdrawal, understanding the entrainment mortality of trout in the Gros Ventre River is important for the conservation of local trout populations.

The species of interest in the Gros Ventre River is the Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*) and is designated as a “species of special concern” or “sensitive species” by a number of state agencies and conservation groups within the Rocky Mountain west. Although the Yellowstone cutthroat trout has recently avoided federal listing because of robust headwater populations (USFWS 2006), they face continued threats across their range. The fine-spotted Snake River native trout is a morphologically divergent ecotype of the Yellowstone subspecies and the Gros Ventre and Snake River in the Grand Teton National Park is the last remaining core habitat for the fine-spotted Snake River cutthroat trout (Hayden 2005). Thus, understanding the threat that irrigation canals pose for the conservation of Snake River cutthroat trout population within the Gros Ventre River is an important fisheries and conservation objective.

Our objectives were to: (1) explore which species are being entrained, (2) examine the spatial and temporal patterns of Snake River cutthroat trout entrainment, (3) determine whether canals are a large source of mortality or whether cutthroat use the canals as temporary habitat during the irrigation season, and (4) investigate the potential population impact of entrainment to the Gros Ventre River Snake River cutthroat trout population.

Methods:

Study area:

The Gros Ventre River is a major cobble-bed tributary to the Snake River approximately 8 km north of Jackson, Wyoming which drains approximately 1554 km^2. Our study area comprises the lower 19km of the Gros Ventre River, bounded on the east by the Grand Teton National Park boundary and on the west at the confluence of the Gros Ventre with the Snake River (Figure 1). There are multiple irrigation canals in this stretch of river. In the lower river, water withdrawals and natural seepage losses can substantially reduce instream flow of the Gros Ventre River along the lower 6 to 10 km section (Campbell and Lasley 1990). During low water years, these conditions may impair habitat, fragment the Gros Ventre from the Snake River, and convey downstream migrating fish into irrigation canals. Only a small number of these irrigation canals have return channels and none of these canals have fish screens.

Previous studies have indicated that Snake River cutthroat trout, rainbow trout (*Oncorhynchus mykiss*), rainbow x cutthroat trout hybrids, mountain whitefish (*Prosopium williamsoni*), brook trout (*Salvelinus fontinalis*), Utah sucker (*Catostomus ardens*), mountain sucker (*Catostomus platyrhynchus*), bluehead sucker (*Catostomus discobolus*), mottled sculpin (*Cottus bairdii*), paiute sculpin (*Cottus beldingii*), longnose dace (*Rhinichthys cataractae*) and speckled dace (*Rhinichthys osculus*) are present in the lower portions of the Gros Ventre River (Novak unpublished data).

What species are being entrained?

To describe which species were entrained and to select our focal canals, we sampled all canals diverting water from the lower Gros Ventre River during the 2007 irrigation season. We surveyed downstream from the diversion point within four days after headgate closure (water inflow was terminated), but while water remained in the canal. Even though sampling length was limited by access to private lands, we sampled distances of at least 2km downstream of the diversion point in every canal. Fish in irrigation canals have been reported to congregate immediately downstream from head gates when flows subside (Clothier 1953). Similar to expectation, we found that the number of fish collected decreased with distance from the point of diversion. We used dewatered sections as barriers and performed multi-pass depletion sampling until we completely depleted native trout species (no trout were captured in last pass, typically 2 to 3 passes) in the reach. We identified, counted, and measured (total length: TL, mm) all fish. In 2008, we followed the same procedures on the five canals with the highest fish densities in 2007. We used descriptive statistics to assess community composition of entrained fish and compared relative abundances to determine which canals entrained the most fish. This information was also used to choose our focal canals for cutthroat trout entrainment estimation.

When and what proportion of the population is lost?

We used both trap nets and fixed antennae on our focal canals to determine when cutthroat trout were being entrained, what proportion of trout were temporarily using habitat within canals, and what proportion of the Snake River cutthroat trout population were permanently entrained (Appendix 1). Upstream and downstream facing trap nets were deployed in 3 canals during the summer of 2007 (Spring Gulch, Enterprise, and White) and in two canals (Enterprise and Glidden) in 2008. Trap nets were checked every morning, fish were measured (TL, mm), checked for tags, and released back into the canal in the direction they were headed. In addition, we established fixed antennas in three canals (Spring Gulch, Price Lucas, and White) in 2008. In each canal, we set up two fixed antenna approximately 4m apart to detect directional movement of fish. The antennae (Oregon RFID, ½ duplex) emitted a magnetic pulse and scanned 8 times per second to detect any tagged fish moving through the canal. All information from detected tags was stored in an on-site data logger. We downloaded data, changed batteries, and checked magnetic fields at least weekly to ensure complete detection fields (i.e. detection throughout the entire wetted volume of the canal). During the dates that these systems were deployed, the antennae were functioning 24 hr/day. Fish detected always registered more than 2 readings per antennae and were always detected on both antennae. We did not measure any shift in the antennae or detection field during the summer either year. During the weekly checks the entire wetted volume within the canal was always determined to be within the detection field. Therefore, we feel that all tagged fish moving through the system were detected.

We tagged 616 fish (130 to 604mm) in the Gros Ventre River with 23mm half duplex tags from Oregon RFID over the two year period. We captured trout through electrofishing or angling. We anesthetized fish, made a small insertion ($\leq$0.5mm) below the pelvic fin, and slid the pit tag into the body cavity towards the anus. We tagged fish in collaboration with ongoing population estimate work by Wyoming Game and Fish (150 fish in Sept 2007, 41 fish in April 2008, 226 fish in August 2008, and 149 fish in Sept 2008) from the National Park Service and USFS boundary to Kelly. In addition, 51 fish were angled and tagged between Kelly and the Gros Ventre Campground in August 2008 to increase the coverage of marked fish in the lower reaches of the river.

We examined the seasonal timing of fish movement into canals by describing the capture rates of fish in the trap nets and detections of tagged fish at our fixed antennae stations. To calculate the percentage of fish that temporarily used canals (moved in then back out) and the length of time trout spent in canals during the irrigation season, we only used detections at fixed antennae stations. This eliminates any potential capture bias associated with reduced recaptures at trap nets because of trap avoidance or injury.

We determined the proportion of the Gros Ventre River cutthroat population that was entrained by examining what proportion of the fish tagged in the river were detected in the canals (trap nets or fixed antennae). A concurrent radio-telemetry study of cutthroat trout in the Gros Ventre River indicated that few trout tagged above Kelly moved below the diversion structure (<25% of fish moved downstream; Gregory and Yates 2009). Since all irrigation canals are downstream of Kelly, fish that we tagged above the structure have a substantially lower probability of encountering an irrigation diversion point and becoming entrained than fish tagged below the structure, so we estimated entrainment for fish above and below the structure separately. We used a mark-recapture approach to determine what proportion of the population was entrained. We divided our study into 4 periods, each period began with a major tagging events associated with Wyoming Game and Fish population surveys (Sept – Nov 2007; Apr-Aug 2008; Aug-Sept 2008; Oct-Nov 2008). We applied three potential survival rates of 42%, 64%, 86% (average ± 2 standard deviations from Carlson and Rahel 2007; Appendix 2) to account for mortality of tagged fish between periods. For each period, we divided the number of trout detected by the number of tagged trout estimated to be alive during that period to determine what proportion of the population was detected to be entrained in these focal canals. We reported this range of values to encompass our uncertainty in the mortality of tagged fish among our tagging and recapture periods. We converted these estimates of the percent of the population entrained during the irrigation season into annual mortality by (1) transforming our estimated entrainment mortality (A_{period}) for each capture period into daily instantaneous mortality (Z_d)(e.g., $Z_d = (-\log_e(1 - A_{period}))/\text{days in period}$, (2) summing it across the year (($\sum_{\# periods} Z_{day} * d_{in\_period}$) in other words we multiplied the daily instantaneous mortality*days for each capture period and summed across the capture period, including no entrainment mortality for the time period outside of the irrigation season), and (3) transforming annual instantaneous mortality to annual mortality (e.g., $A_{annual} = 1 - e^{-Zannual}$)).

Population modeling simulations

We used a stage–structured matrix population model to simulate different scenarios to explore potential impacts of these mortality sources to the overall population. Stage-structured models have been valuable for comparing management scenarios to provide insights into assessing the potential importance of specific demographic changes to species of conservation interest. We constructed a density-independent, stochastic, closed, post-birth pulse matrix model with four separate stage classes, young of the year (YOY), subadult, small adults, and large adults. These stages were chosen because of their different mortality and fecundity rates (see Hilderbrand 2002, Stapp and Hayward 2002). We surveyed the literature for published demographic rates of Yellowstone cutthroat trout. Using the mean, variances and distributions of demographic parameters for cutthroat from the literature review (Table 1) and our entrainment mortality estimates, we developed five scenarios to evaluate the impact of additional mortality from fish loss to irrigation canals. We modeled environmental stochasticity by randomly varying each vital rate around the mean vital rate value. Vital rates were drawn from a beta distribution (survivorship and breeding probabilities) or stretched beta values (fecundity values). To estimate the standard deviation that is required to compute a beta distribution, we obtained ranges of values for vital rates reported in the literature, then divided the reported range by four to estimate standard deviation. We entered mean demographic rates and associated variance estimates into a modified version of VitalSim (Morris and Doak 2002), a population viability model coded in MatLab. Because our goal behind population scenarios is to examine the range of possibilities associated with increased adult entrainment mortality, we modeled a baseline scenario and a low (2%) and high (6%) estimate of adult cutthroat entrainment mortality to determine the relative differences of the results from the baseline scenario to those scenarios considering additional entrainment mortality. Two additional scenarios included increased mortality estimates on the subadult stage, in addition to the adult life stages. Even though few subadult fish were tagged, subadults (< 150m) made up over 50% of the cutthroat catch, therefore we were compelled to explore the impacts of including entrainment of this life history stage as well. These scenarios provide a context for how the estimated changes in annual mortality may alter population dynamics. We evaluated these scenarios by examining differences in population growth rates and number of fish in the population or fisheries productivity.

Results

What species are being entrained?

Over ten different fish species present in the river were also captured in the canals. The trout species of concern (Snake River cutthroat trout) was only a small portion of the total number of individuals captured (Table 2). The most abundant group of fish captured in the canals were cyprinids (longnose dace, speckled dace, and redside shiner), followed by catostomids (longnose suckers, Utah suckers) and cottids (sculpin sp.). Cutthroat trout only represented 8.0 and 9.2% of the total catch in 2007 and 2008, respectively. We captured a large range of life stages of most species in the canals (Table 2), including a large size range of Snake River cutthroat trout (Figure 2). Overall, the larger canals with the highest discharge seemed to entrain the most fish. This observation was not analyzed statistically because of the confounding effects of accessible area, timing of headgate closures, date when discharge vs. fish were estimated, and summertime habitat quality or survival within the canals. For example in 2007, the entire river was flowing into Spring Gulch canal for a large portion of the summer but this canal had shortest accessible length to sample (Appendix 3). In addition, South Park Supply's headgate closed in the beginning of July in 2007 and the middle of September in 2008 resulting in different captures of trout.

When are cutthroat trout being entrained?

We focused our examination of the temporal patterns of Snake River cutthroat entrainment on Spring Gulch canal because it had the most continuous data of any station: it had a trap net operating from Aug 4 to September 24 in 2007 and a fixed antennae functioning continuously throughout the period of diversion from May 12 – October 2, 2008. Because of large woody debris movement during high flows, animal destruction, and periodic flows other fixed station and antennae sites had more periodic data (Appendix 2).

Few adult cutthroat trout were entrained into Spring Gulch canal from spring through mid-summer, but numbers increased in late summer and fall (primarily August and September). Several adult trout were detected in Spring Gulch canal in June, but those fish moved back out into the river. The trap net data indicate that juvenile cutthroat trout (<100mm) were entrained through the end of the September sampling period (Figure 3). Of all of the tagged fish that entered irrigation canals, 38% moved back into the river before the head gate closure. The average time that fish spent in canals (and were detected returning to the river) was 7.5 days and the longest time was 22 days. Fish that spent more than one week in canals were typically not detected again. The short period of time that surviving fish spend in canals indicate these areas are not adequate summertime habitat. In addition, habitat surveys conducted during 2007 using methods developed by Wyoming Department of Environmental Quality (WDEQ 2004) indicated that canals are not high quality habitat compared with other nearby creeks that have also been assessed (Appendix 4). Instantaneous water temperature readings taken during habitat sampling averaged 20°C (maximum 26°C, unpublished data & 2007 field season report). These measurements are below the critical thermal maximum for Snake River cutthroat trout (29.6°C, Wagner et al. 2001) and within the range of temperatures that Yellowstone cutthroat trout are reported but above their optimal temperatures (Greswell 1995).

Analyses of tagged fish: what proportion of the population is lost?

By considering only tagged fish that enter these canals and were not detected again, we can estimate what proportion of the population was lost. We developed estimates for fish tagged above and below the Kelly diversion separately because of a concurrent study of cutthroat movement patterns in the system indicated a distinct break with few fish that were tagged above Kelly moving past the Kelly diversion point (Gregory and Yates 2009). Estimates of entrainment varied for each capture period and ranged from 0.5-7.3% for fish tagged below the Kelly diversion structure and 0-3.2% for fish tagged above the structure (Table 3). Converting these estimates to annual mortality indicated a potential increase in annual mortality of 3-6% for trout below the diversion and 1-2% for trout above the diversion.

Population modeling simulations: so what?

Assuming entrainment mortality is additive to natural and fishing mortality rates, increasing mortality by 1-6% can have substantial implications for population numbers and population growth rates (Figure 4). In comparing the differences in the stochastic population growth rates, entrainment could reduce population growth rates in the lower Gros Ventre River by 1 to 10% with entrainment mortality. Although these differences in population growth rates may appear small, population sizes with these different population growth rates projected just 25 years forward from the same starting point result in substantially lower abundances than if there was no additional entrainment adult mortality. If we consider additional subadult mortality these differences are even greater (Figure 5). The lower estimates reflect the entrainment mortality for those fish tagged above the Kelly diversion and the higher estimates reflect the likely effects of entrainment on those fish tagged below the Kelly diversion.

Discussion

Similar to other studies, nongame fish dominated the composition of our catch in irrigation canals (e.g., Post et al. 2002). We did not find any nongame species of concern for the region in canals, but catches were composed of relatively common species. Unfortunately, we do not have size-structure information or population estimates of these fish species in the river, so we cannot assess the relative importance of entrainment for these species. The only species of concern entrained was Snake River cutthroat trout; therefore, we focused our quantification of impact on this trout population.

Irrigation diversions can have multiple impacts on a system that might influence cutthroat trout including the loss of river habitat, creation of summertime backwater habitat and direct entrainment mortality. Many years natural losses to the alluvium combined with irrigation diversions cause the Lower Gros Ventre River to be dewatered in August through October (Gwen Gerber in review). Anthropogenic effects of water diversion increase the frequency or number of years that the river is dewatered (Gwen Gerber in review). Thus, irrigation diversions do play a role in reducing river habitat availability and fragment the Gros Ventre River from the Snake River habitat. Given the naturally dynamic state of this river section, specifically its mobile substrate, and naturally shallow or dewatered sections, it is unlikely that this section of river provides high quality summertime habitat (e.g., mobile bottoms have low invertebrate production, shallow wide areas have warm water temperatures). Therefore, our major concerns for fish are primarily associated with increasing entrainment mortality.

Although fish do move into irrigation diversions, they are not providing quality summertime habitat. Only 38% of tagged trout that swam into the diversions were detected moving back out of these systems. The ability of fish to leave these canals is typically dependent upon the hydraulics at the headgate structure itself, the swimming capabilities of the species, potential return channels, and the presence of behavioral cues to leave the canals. Other studies have found similar patterns to this study, Megargle (1999) found 40% of entrained radio-tagged rainbow trout navigated back to the mainstem through headgates; Roberts (2004) detected 20% of radio-tagged Bonneville cutthroat trout returned to the river; Gale (2005) found 11% of entrained radio-tagged westslope cutthroat returned; and Roberts and Rahel (2008) estimated 20% of Bonneville cutthroat and 23% of brown trout in Smith’s Fork (WY) returned to the river. In the Gros Ventre River, fish that left the canals spent an average of 7.5 days in the canals before returning to the river. The residence time of fish (before leaving or dying) in canals likely depends on water conditions that vary by season, year, and canal. Our estimate of residence time in canals was similar to the 9 day estimate of evacuation rate observed by Post et al. (2002).

Given the short residence time of trout in canals and their relatively low quality of habitat, canals along the lower Gros Ventre River do not provide quality summertime habitat.

Since less than one quarter of the cutthroat trout that were radio-tagged above Kelly in a concurrent study moved downstream (Gregory and Yates 2009); we think that there is some separation of the cutthroat reproducing above and below Kelly. For Snake River cutthroat trout spawning populations above Kelly increases in annual mortality from entrainment were relatively low (<3%). In contrast, increases in annual mortality due to entrainment were relatively large (up to 8.6%) for trout in the section of the Gros Ventre River below Kelly. We do not expect a basin-wide population impact of entrainment on the Snake River cutthroat in the Gros Ventre River. We might expect some localized population impacts in the lower river section, because of the relatively high entrainment of fish tagged downstream of Kelly. As in any modeling exercise, we made assumptions to determine the potential relative importance of the entrainment mortality. Specifically, we made assumptions about (1) baseline mortality rates given previous studies of Yellowstone cutthroat trout in the region, (2) additive entrainment mortality because there are no established density-dependent relationships for this system, and (3) played out scenarios for closed populations (no dispersal, implies site fidelity to spawning areas) above and below Kelly. Even though we analyzed a range of estimates of annual mortality to explicitly demonstrate some of this uncertainty, our entrainment estimates are likely underestimated for the system. First, not all canals were monitored throughout the entire irrigation season. We had five major canals monitored during the time frame (August through October) of peak entrainment losses, but we were not able to monitor entrainment through the entire season for every canal. For example South Park Supply canal is a large canal with a high discharge, but was open much later than expected in 2008 and was not included in our estimate of entrainment. Second, our entrainment estimates were from the 2008 irrigation season. This was a year with average to above average snowpack and precipitation resulting in river flows maintained throughout the summer. In 2008, there was always water in the river channel while in 2007 the entire surface flow of the lower river was diverted into Spring Gulch canal. Given flow conditions, we expect estimated entrainment rates in the Gros Ventre River to have been relatively low in 2008 compared with 2007. Finally, we only included an additional mortality on a subset of the life stages (subadults and adults) in our population modeling that we encountered in the canals during our fall closure surveys.

We incorporated entrainment mortality into the older, larger life stages because we had estimates of entrainment for these groups. Our tagging efforts were in collaboration with the Wyoming Game and Fish raft electrofishing population surveys. The average size of fish pit tagged was 337mm and well above the median size of fish detected in our trap nets or headgate closure surveys (Figures 2 and 3). To examine the potential of including subadult entrainment, we simulated the consequences if the entrainment rate was similar to the adult rate that we did have data to estimate. Depending on the system (e.g., population structure, location, discharge, irrigation season versus species life history), canals may entrain high percentages of larger or smaller fish. For example, several studies have found that canals entrain primarily large fish (Roy 1989, James 1990, Carlson and Rahel 2007), while others documented high percentages of age 0 or age 1 fish (Gebhards 1959, Hallock and Van Woert 1959, Fleming et al. 1987, Gale 2005, Post et al. 2002). We detected higher catches of adult fish in August but observed a pulse of fish in the late summer and early fall that were between 80 and 120mm (likely age 1; Figure 3). These life stages were not included in our entrainment rates because we don’t know what proportion of the population these individuals composed. The transition probabilities of young of the year to subadults and subadult to small adults are the two parameters with the highest elasticity for our matrix model. Transition probabilities are the probability that an individual survives and grows enough to move to the next stage class. Elasticity provides an index of how sensitive the population growth rate is to changes in that parameter. This is a sensitivity analyses with higher elasticities indicating higher impacts on population growth for the same proportional shift in the parameter. Therefore, if we reduce survival (i.e. add entrainment mortality) on young of the year and subadult fish, we would expect to see even greater impacts on population growth rates and abundances.

For the upper sections of river above Kelly our estimates of entrainment are similar to previous basinwide estimates (1.5-3.5%, Post et al. 2002, Carlson and Rahel 2007), but below Kelly they are substantially higher. Thus, entrainment is not likely to cause basin-wide collapse, but have localized impacts on population productivity. In addition, given that the canal entraining the most fish is Spring Gulch, the most downstream canal in the system, entrainment is biased toward the migratory life history. Increases in mortality for the migratory life history may result in lower survival in this life history strategy potentially promoting a resident life history. This biased mortality may be viewed as problematic because diverse life history strategies (maintaining migratory life history) are important for the long term conservation of fish populations. In addition, migratory fish are often larger and therefore produce a more appealing fishery.

The mix of mark-recapture and population modeling was a useful approach to estimate both a watershed level and more localized levels of entrainment for the Gros Ventre River population. For example, in this study there is not a problem for the basin-wide Snake River cutthroat trout populations, but is may reduce fisheries production associated with the river sections below Kelly.

Recommendations:

1) Snake River cutthroat trout is the species of concern for entrainment

2) The majority of entrainment leading to mortality is occurring between August and September for adult trout and likely later September and October for younger (age-1) trout. Thus closures of head gates in August could reduce much of the entrainment.

3) Spring Gulch has the highest entrainment rate and is the highest priority for a solution, but South Park Supply, White Complex, and Price and Lucas are also entraining large numbers of fish.

4) The entire size range of trout is entrained so any structure to minimize entrainment should be effective for the size range of fish (50-500mm).

Table 1. Mean parameter estimates for the different scenarios used to evaluate entrainment mortality. Scenarios were the lower estimate for entrainment mortality (decrease survival by 1%) and the higher estimate for entrainment mortality (decrease survival by 6%) on adult life stage only and then with subadult and adult life stages. Distribution of the parameter estimates and the reference for the parameter are indicated.

Stage	Baseline (Range)	Distribution	References
YOY			
Survival	0.027 (0.02-0.034)	Beta	Stapp and Hayward 2002
Subadult			
Survival	0.19 (0.17-0.57)	Beta	Stapp and Hayward 2002
Transition	0.19 (0.17-0.57)	Beta	Stapp and Hayward 2002
Small Adult			
Survival	0.21 (0.2-0.62)	Beta	Carlson and Rahel 2007
Transition	0.21 (0.2-0.62)	Beta	Stapp and Hayward 2002
Probability of breeding	0.4 (0.35-0.75)	Beta	Meyer et al. 2003b
Fecundity	506 (304-708)	Stretched Beta	Meyer et al. 2003b
Adult			
Survival	0.35 (0.2-0.62)	Beta	Carlson and Rahel 2007
Probability of breeding	0.5 (0.35-0.75)	Beta	Meyer et al. 2003b
Fecundity	919 (552-1287)	Stretched Beta	Meyer et al. 2003b

Table 2. The species composition and size range for fish captured in the irrigation canal closure surveys in 2007 and 2008. In 2007, we did not differentiate the two sucker species, so they are listed as unknown sucker. Similarly if the observer did not distinguish between longnose or speckled dace, they were listed as unknown dace. Unknown trout is composed of smaller individuals when the observer could not distinguish a cutthroat from a rainbow trout or hybrid. NA indicates no data is available for category. All (*N*) is the total number of fish captured during the survey for each year.

Species	Species composition 2007 (%)	Species composition 2008 (%)	Size Range (mm) 2007	Size Range (mm) 2008
Longnose dace	17.9	16.7	12 - 126	18 – 96
Speckled dace	13.2	4.2	10 – 118	21 – 76
Unknown dace	4.9	14.8	17 – 121	15 – 96
Redside shiner	3.9	6.9	26 – 111	38 – 111
Utah sucker	NA	4.1	NA	38 – 140
Mountain sucker	NA	4.0	NA	36 – 164
Unknown sucker	16.6	10.4	10 – 390	22 – 58
Sculpin sp.	31.2	14.4	14 – 122	32 – 99
Mountain whitefish	2.2	6.0	49 – 270	79 – 202
Cutthroat trout	8.0	9.2	41 – 570	58 – 530
Rainbow trout	0.2	1.0	125 – 135	102 – 288
Brook trout	0.2	0.5	70 – 97	102 – 265
Unknown trout	1.7	7.5	29 – 51	38 – 80
Other	0	0.1	NA	100
All (*N*)	2686	1240		

Table 3. Percent of the population permanently entrained for fish tagged above the Kelly diversion and below the Kelly diversion for the different mark-recapture time periods. NF indicates no fish were tagged below Kelly until the end of period 2 (end of July 2008).

	Above Kelly			Below Kelly		
	Low	Average	High	Low	Average	High
Period 1: Fall 07 (30 days)	0.67	0.69	0.70	NF	NF	NF
Period 2: Spring 08 (76 days)	0.71	0.93	1.37	NF	NF	NF
Period 3: Sum 08 (61 days)	1.73	2.00	2.38	6.5	7.4	8.6
Period 4: Fall 08 (30 days)	0.21	0.24	0.29	2.3	2.8	3.5
Annual Mortality (%) Baseline	46	66	83	46	66	83
Annual Mortality(%) incl. entrainment	48	67	84	52	70	86

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Figure 1. Map of the Gros Ventre River study section bounded by the park service boundary to the confluence with the Snake River. There is a diversion dam at Kelly. Irrigation canals that were active are shown and the sampling sites for our trap nets and fixed antennae are indicated.

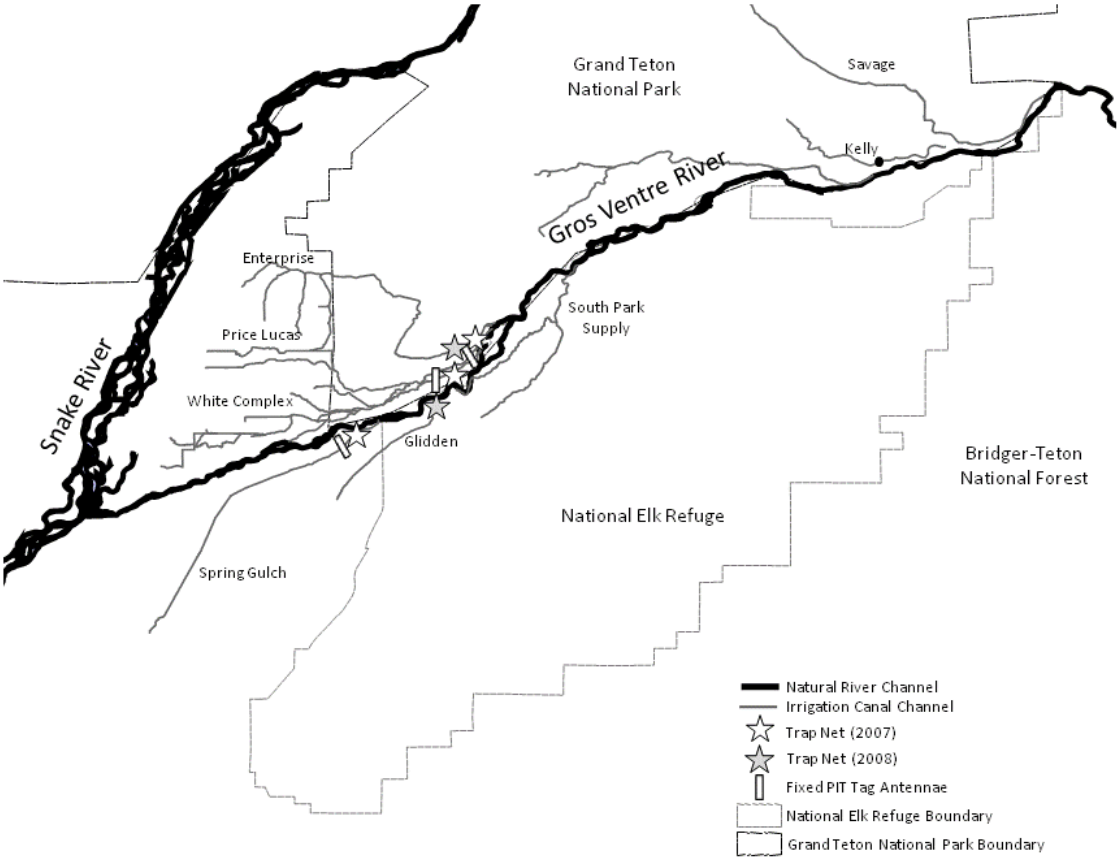


Figure 2. Length frequency histogram of Snake River cutthroat trout in the canals during the closure surveys for 2007 and 2008 combined.

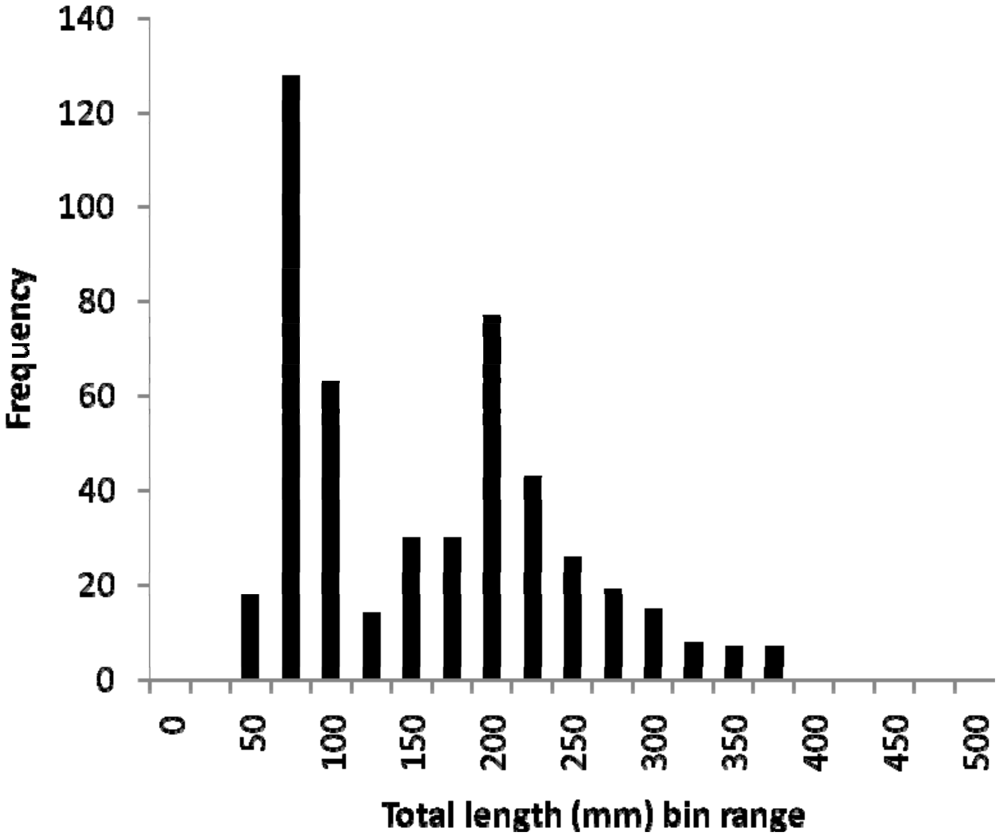
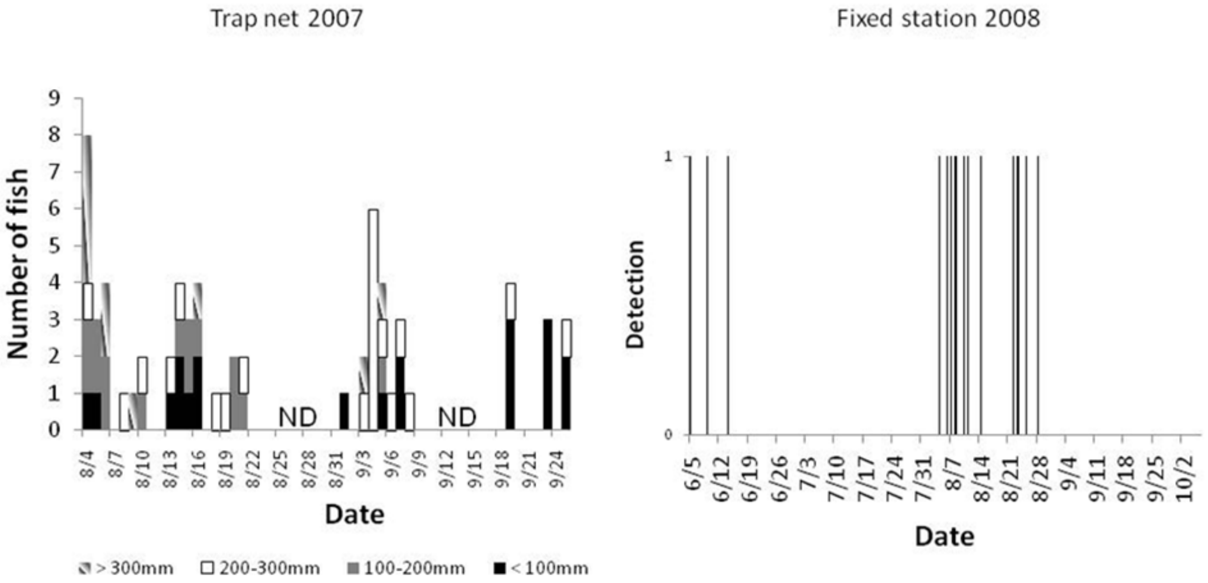


Figure 3. Entrainment of Snake River cutthroat trout into the Spring Gulch canal during the 2007 and 2008 irrigation seasons. In August and September of 2007, we estimated entrainment with a trap net. ND indicates dates that the net was not fishing. In 2008, we placed a fixed station in this irrigation canal to detect cutthroat tagged in the river. The mean size of tagged fish was 337mm. Fish entered Spring Gulch in June but returned to the river, whereas tagged trout that entered Spring Gulch in August remained in the canal.



Trap net 2007

Fixed station 2008

Figure 4. Differences in the mean log lamba (+ 1 standard deviation) over 200 runs of our stochastic model. The differences between our scenario without entrainment and those with our low estimates of entrainment (1%) are minor, but if entrainment alters annual mortality by 6% we expect significant impacts on population growth rates. The stochastic population growth rates associated with the different scenarios are 1.08, 1.06, 1.01, 1.05, 0.95 for no entrainment, -0.01 Adult, -0.06 Adult, -0.01 Adult and Subadult, and -0.06 Adult and Subadult respectively.

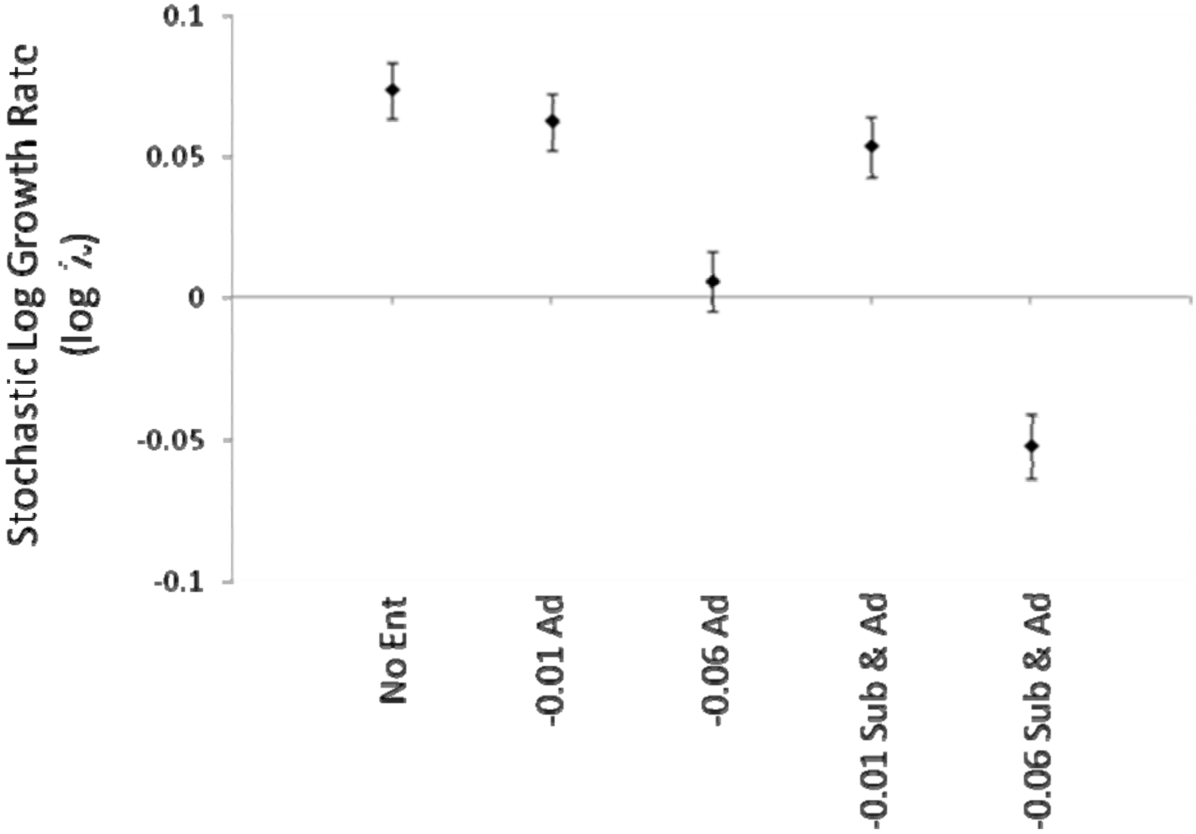
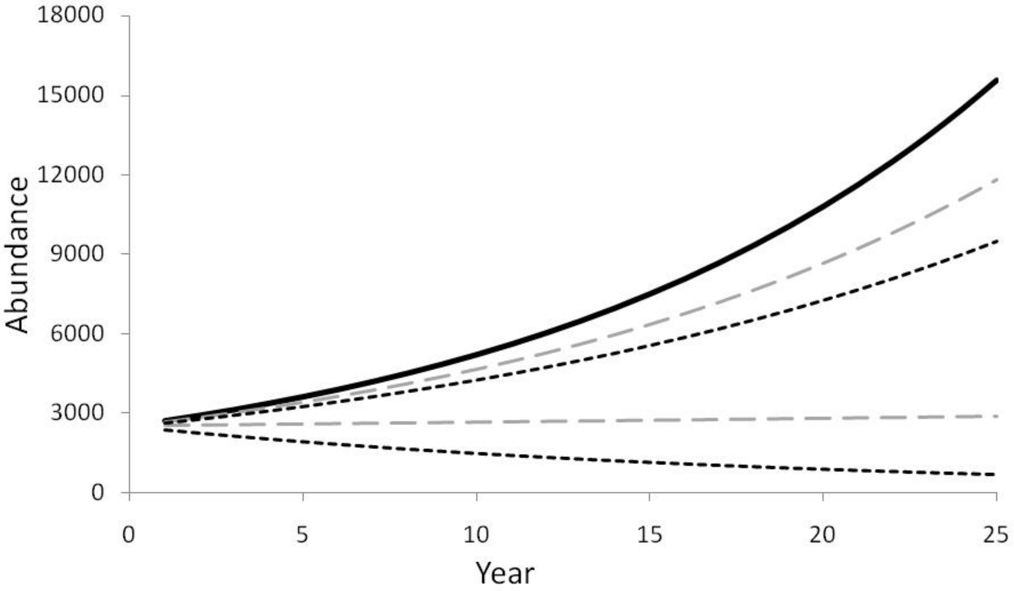


Figure 5. Model projections for differences in fish abundance using mean population growth rate over a 25 year period to indicate the potential loss of fisheries production. The dark, bold line is a projected population with no additional entrainment mortality in the model. The gray dashed lines reflect the projections from the high and low scenarios of adults. The projections indicate that the potential loss from entrainment of adults could reduce abundances by 24-89%. If we include mortality on subadults as well as adults and project our low and high estimates of entrainment for 25 years, entrainment could reduce abundances between 39-96% as represented by the differences between the black bold line (no entrainment) versus the black dashed lines (low and high estimates of entrainment on adults and subadults).



Appendix 1. Description of what irrigation canals were sampled the different years and with what type of gear. All canals listed were electrofished after headgate closures in 2007 and 2008.

Canal	Gear Type	Dates operating	Year	Information
Spring Gulch	Trap Net	July – September (8/4-8/21,8/30-9/8, 9/18-9/27)	2007	Timing
Spring Gulch	Fixed Station	May – Oct (5/15 – 10/6)	2008	Timing, % pop
Enterprise	Trap Net	July – September (8/14-8/21, 9/5-9/8, 9/19-9/27)	2007	ND flows erratic
Enterprise	Trap Net	July – September (5/26-6/2, 6/9-6/12, 7/18-7/24, 7/28-9/30)	2008	% pop
White Complex	Trap Net	July – September (5/15 – 10/6)	2007	ND beaver damage
White Complex	Fixed Station	July – October (7/16 – 10/15)	2008	% pop
Price and Lucas	Fixed Station	July – October (7/8 – 10/15)	2008	% pop
Glidden	Trap Net	July – September (6/12-6/26, 7/13-7/31)	2008	% pop

Appendix 2. All mortality estimates for adult Yellowstone cutthroat trout as reported in Rahel and Carlson (2007). For our adult trout mortality rates we averaged the estimated mortality from the Snake River WY, Bar BC Spring Creek WY, and Fish Creek in WY but the variance estimate was derived from the entire summary of estimates.

Stage	Percent Mortality	Location	Reference
Adult	50%	Snake River,WY	Hayden 1968
Adult	66%	Snake River,WY	Hagenbuck 1970
Adult	61%	Snake River, WY	Kiefling 1972
Adult	46%	Bar BC Spring Cr., WY	Kiefling 1978
Adult	71%	Fish Creek, WY	Kiefling 1978
Adult	53%	Teton River Above Dam, WY	Thurow et al. 1988
Adult	69%	Teton River Below Dam, WY	Thurow et al. 1989
Adult	73%	South Fork Snake River, WY	Thurow et al. 1990
Adult	65%	Willow Cr., ID	Thurow et al. 1991
Adult	69%	Blackfoot River, ID	Thurow et al. 1992
Adult	83%	South Fork Snake River, ID	Thurow et al. 1993

Appendix 3. Description of the irrigation canal, average width, length of canal sampled, trout in canal during the headgate closures, and the percent of our tagged fish that were entrained into the canal.

Canal	Length sampled (km)	Average width (cm)	# trout in headgate closure surveys 2007	# trout in headgate closure surveys 2008	% tagged fish mortality in canal
Spring Gulch	2.2	806	39	18	70
South Park	4.6	759	6	40	NS
White Complex	6.3	407	103	71	12
Price and Lucas	4.6	365	50	74	6
Enterprise	5.7	401	45	24	6
Glidden	3.0	272	9	NS	6

Appendix 4. Results from habitat surveys conducted in summer 2007. Multiple reaches were sampled for each irrigation canal. Canal reaches are arranged in order from top of canal (headgate) to bottom. ENT = Enterprise, BKS, WC1, WHIT = are all sections in the white canal complex, PL = Price and Lucas, May= May, GLD = Glidden, SAV=Savage, SPS = South Park Supply. Channel type indicates whether the canal is channelized (CH) or appears to be an old streambed (SB). Depth was the maximum depth of water at the cross-section at the time of sampling. Temperature is an instantaneous measure at the time of sampling indicated in the next column. Asterisks (*****) for the SPS canal indicated that the wetted width and depth are not flowing conditions but represent the stagnant pools as readings were taken after shut-off. The habitat score is a percentage of the total habitat score from the WDEQ habitat assessment (out of 200). Instream habitat categories are based on notes regarding presence/ absence of LWD, pools, under-cuts and other general habitat features. The last column indicates the habitat parameters that scored less than 50% of the total potential points. Parameters Index: 1) Bottom Substrate- % Fines, 2) Fine Sediment Covering (Embeddedness), 3) In-stream Fish Cover, 4) Velocity/Depth Regimes presence/absence, 5) Channel Flow Status, 6) Channel Shape, 7) Pool/Riffle Sequence, 8) Channelization/ Alteration, 9) Width: Depth ratio, 10) Bank-full Vegetation Protection, 11) Bank Stability, 12) Riparian Zone Disruptive Pressures, 13) Riparian Vegetative Zone Width.

	Channel Type	Bank-full (cm)	Wetted (cm)	Depth (cm)	Temp. (°C)	Time of Day	Habitat Score (%)	Instream Habitat	Parameters with Low Habitat Scores (< 1/2 total)
ENT-1	CH	405	390	30	14.4	10:05	0.49	Poor	3,4,7,8,9,11
ENT-2	CH	372	340	9	20.5	11:54	0.61	Poor	3,4,7,8,9
ENT-4	CH	427	427	31	17.2	10:24	0.53	Poor	2,3,4,7,8,9
BKS-2	SB	642	562	36	23.5	13:31	0.73	Okay	9,10
BKS-1	SB	647	387	16	17.2	10:14	0.69	Okay	5,9
GLD-1	CH	318	318	61	16.6	11:03	0.58	Poor	1,2,4,7,8
GLD-2	CH	295	177	40	22	14:15	0.58	Poor	1,2,4,7,8
GLD-4	CH	203	203	46	21	13:07	0.56	Poor	2,3,4,8,11
MAY-1	CH	266	160	33	17.7	10:52	0.43	Poor	1,2,3,4,5,13
PL-3	CH	453	450	14	18.6	16:23	0.60	Poor/Okay	1,3,4,9
PL-2	CH	322	298	50	17.3	11:25	0.60	Poor/Okay	2,4,6,7,8
PL-1	CH	320	310	40	22.3	18:27	0.59	Poor/Okay	1,3,7,8
SAV-1	CH	385	315	24	20.5	12:44	0.54	Poor/Okay	2,3,4,9
SAV-2	CH	455	395	27	26.5	14:36	0.38	Poor	1,2,3,4,8,9,10,11
SAV-3	CH	442	372	40	22.3	16:26	0.34	Poor	1,2,3,4,8
SPS-4	SB	787	360*	10*	27.5	13:51	0.40	Poor	2,3,4,5,7,8,9
SPS-2	SB	890	684*	6*	17.9	10:44	0.42	Poor	2,3,4,5,7,8,9,11
SPS-1	SB	600	350*	10*	18.7	8:34	0.38	Poor	2,3,4,5,7,8,9
WC1-3	CH	282	215	22	13.4	10:30	0.51	Poor/Okay	3,4,5,7,9,10,12,13
WC1-2	CH	254	200	20	24	13:38	0.67	Poor	9
WC1-1	CH	210	200	21	23.6	15:09	0.57	Poor/Okay	1,2,3,4,9
WHIT-4	SB		686	69	23.7	15:59	0.69	Good	3,6
WHIT-3	SB	903	833	35	15.5	10:31	0.79	Good	3
WHIT-1	SB	388	260	23	16	9:14	0.46	Good	3,4,5,7,10,12,13