Evaluation of an Electric Fish Barrier on the South Canal, an Irrigation Ditch on the Lower Gunnison River, Colorado

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Abstract
An electric fish barrier was installed on the east portal of South Canal to reduce fish entrainment associated with the construction of two hydropower plants in 2012. The objective of this study was to monitor fish entrainment and evaluate the effectiveness of the barrier. Three groups of fish were tagged and released upstream of the barrier; fish from the canal, wild Gunnison River fish, and hatchery reared fingerlings. Mark recapture boat electrofishing was completed and population estimates were made with the Huggins Closed Capture model using fish length to model capture probabilities. The study reach contained 2,994 ± 1,043 fish (>150 mm) in October 2011, 1,764 ± 279 in October 2013, 1,224 ± 239 in July 2014 and 1,900 ± 379 in October 2014. Fish population estimates have declined after the electric barrier, significantly at the 95% level for brown trout but not for rainbows. A total of 288 tagged fish less than 300 mm and four fish greater than 300 mm were recovered below the barrier, representing 1.3% of all tagged fish. The electric barrier appears to meet its objective and successfully exclude larger fish from the study reach, but not smaller age 0, age 1, or age 2 trout. The entrainment, growth and survival of smaller fish maintains a stable population of fish in the canal, but fewer entrained mature fish is likely a benefit to the fish population of the Gunnison River. Further study is needed to evaluate if smaller adult trout can be successfully excluded by the electric barrier with operational modifications.

There are over 105,000 irrigation structures on rivers and streams across Colorado, most in fish bearing waters. Fish entrainment in irrigation canals is known to be a large problem in the western U.S. (Carlson and Rahel 2007) and the loss of fish in irrigation canals has been shown to be a population sink for trout in Wyoming (Roberts and Rahel 2008). The impact of fish lost to irrigation canals on fish populations in Colorado is unquantified. The South Canal is an irrigation ditch in southwest Colorado that diverts an average of 360,600 acre feet of water each year, about 857 cfs average daily flow March-November, from the Gunnison River for agriculture (Bureau of Reclamation 2012). The river contains a Gold Medal trout fishery despite documented entrainment of fish for many years in the canal. The construction of a hydropower plant was expected to increase mortality of entrained fish so an electric fish barrier was installed at the diversion structure in 2012. From the diversion structure and barrier, the canal travels through a 5.7-mile-long tunnel before egressing approximately 0.5 miles above the power house (Figure 1). There is a total of 7.7 miles of earthen canal that contains the majority of fish that are entrained from the Gunnison River. The canal diverts water from March through November each year with the amount of water depending on water supply and irrigation demand. During winter months the canal is generally shut off with only a very small amount of flow as a result of accretions and seepage. About twice a month it is partially opened to run approximately 100 cfs through the canal for 24-48 hours to fill a drinking water supply reservoir. Because of low and intermittent flows in the canal, fish survival over winter was generally thought to be low but variable year to year depending on frequency of freezing temperatures. However, in the winter of 2012-2013, a constant flow of 20-25 cfs was run all winter long to keep water supply reservoirs full during construction of the hydropower plant. This resulted in what appeared to be a much larger number of fish in the canal in spring of 2013 due to increased survival of entrained fish.

The study reach for this project was downstream of the concrete drop below the West Portal (just below the first powerhouse) and was 0.72 miles, ending at the 2nd concrete drop structure (Figure 2, UTM NAD83 258703, 4262335). The canal averaged 46.1 feet wide with 20-25 cfs in March 2013 and 70.2 feet wide at 540 cfs in October 2013. The study reach represents 9.4% of the total earthen portion of the South Canal but is suspected of containing the highest density of entrained fish due to its proximity to the West Portal. While fish routinely pass through the high velocity concrete portions of the canal, the majority of fish reside in the lower gradient earthen portion of the canal.

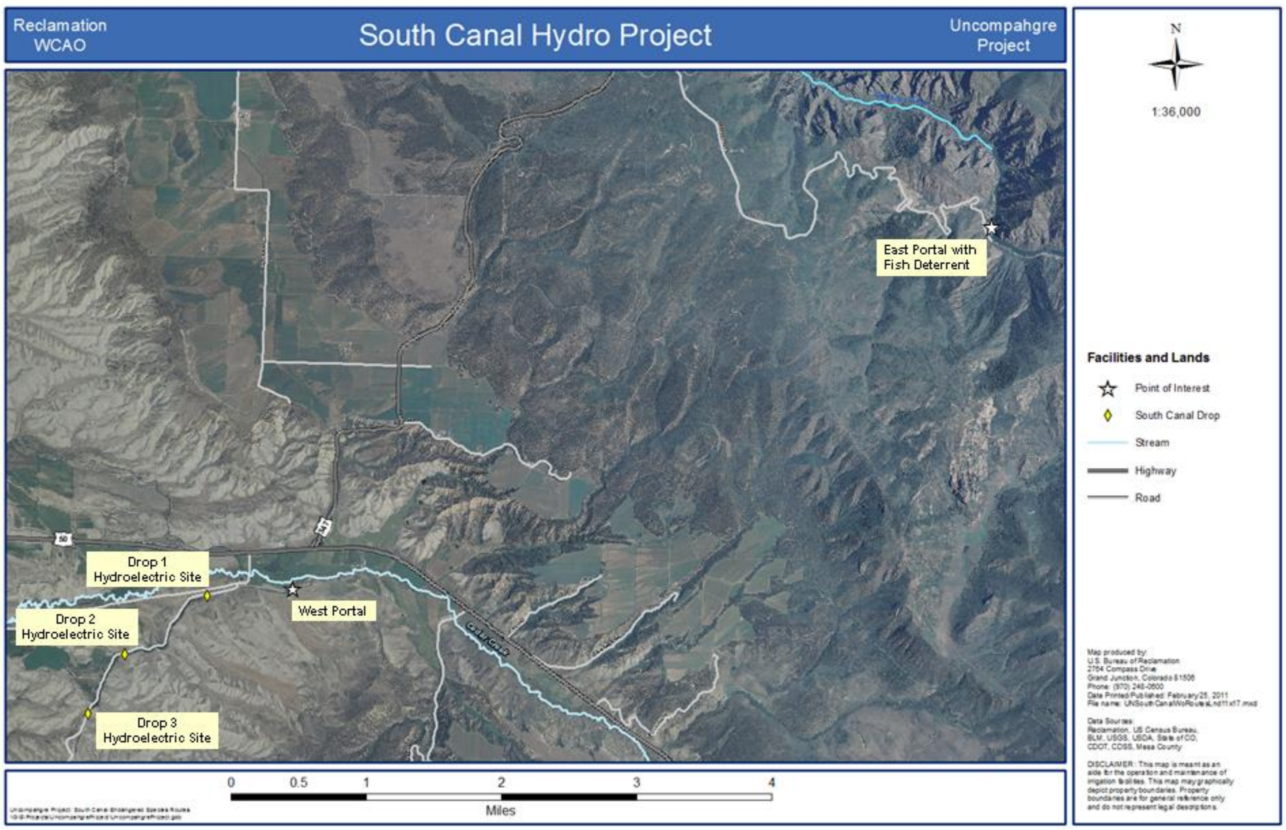

Figure 1. Area map of the Gunnison Tunnel and South Canal (Bureau of Reclamation 2012). The study site is between the West Portal and Drop 1.

The fish barrier was constructed in 2012 and was operational before the 2013 irrigation season. It consists of a series of vertically suspended electrodes across the east portal of the Gunnison Tunnel (Figure 3). The waterway at the barrier is 74 ft wide, 16 ft deep, and has water velocities between 0.2-0.7 m/s (0.66-2.3 fps) and conductivity of 180 µs/cm. The system is powered by three 1.5 KVA Smith Root pulsators with a max power output of 4.5 kW and is designed to operate with a frequency of 2Hz, pulse width of 0.005 s and a field strength of 1v/inch (0.4v/cm). The barrier was designed to exclude "brood stock" rainbow and brown trout but target size was not specified (Smith Root 2011). The barrier is believed to have operated continuously as planned throughout the entire 2013-2014 irrigation seasons. Communication has been lost for brief time periods (i.e. 6 out of over 6,000 hours of operation in 2013) but operation of the barrier was thought to be unaffected and it is assumed that is has functioned continuously during irrigation season the last two years (J. Heneghan, personal communication).

The purpose of this study was to estimate fish populations in the South Canal before and after the barrier and investigate the entrainment of fish from the Gunnison River. To accomplish this, fish population estimates were compared before and after the barrier was built over different seasons and across years while tagged fish were used to document any movement across the barrier.

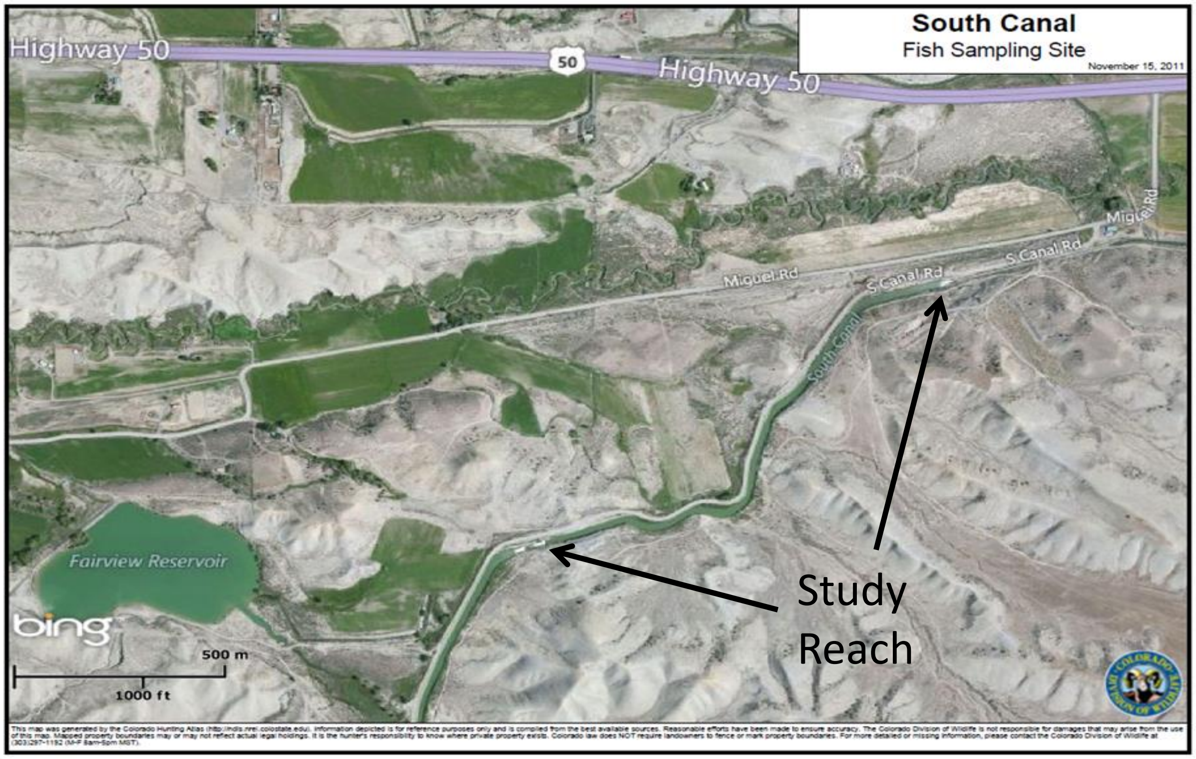

Figure 2. Fish sampling site on the South Canal. The sampling reach was 0.72 miles long (3,802 feet) and was between the first and second concrete drop structures below the West Portal.

METHODS

South Canal was sampled with mark-recapture electrofishing (October 2011, October 2013, July 2014 and October 2014) and multiple pass removal (March 2013) to estimate fish populations of adult and juvenile trout. The study reach for all three occasions was the same but differing methods were used in the spring sampling because of the different habitat and flows when water is not being diverted (20-25 cfs vs. 500-900 cfs).

On March 29, 2013, the canal consisted of two distinct habitat types, consisting of the concrete stilling basin just below the first drop and the earthen portion of the canal below. The density of fish was much higher in the stilling basin and the physical habitat dictated that different sampling methods be used in the two locations. The reach was stratified by habitat types and two sampling reaches were chosen. The entire stilling basin was sampled with 50 ft. bag seine that was 6 ft. deep with 1/8 in. mesh. Multiple seine hauls were made through the stilling basin so a depletion population estimate could be made (Zippin 1956, White et. al 1982). Fish were held in a live pen and then measured for total length to the nearest millimeter. Capture probability was high (estimated to be 0.74 for rainbows and 0.79 for browns) and model assumptions of closure appeared to have been met due to the isolated and simple structure of the stilling basin. The high capture probability and lack of evidence of size selectivity of the seine is expected to help meet assumptions of the removal model and there was no evidence in the data to indicate an unacceptable amount of bias. The portion of the canal below the stilling basin consisted of shallow, slow moving channel that was 46.1 ft. wide 3,528 ft. long. A sampling reach was randomly chosen in this portion of the study reach that was 1,000 ft long and block nets were used to ensure closure. Five Smith Root LR24 backpack electrofishers were used to complete a two pass removal population estimate. Fish were held in a live pen and then measured to nearest millimeter and weighed to the nearest gram, and then returned to the canal. After the March estimate, 876 fish were removed from the canal in an effort to depopulate the study reach before the barrier's first season of the operation. One hundred and twenty-five fish from the stilling basin were tagged with coded wire tags (CWT) and adipose fin clips and transported by aerated fish truck to the Gunnison River in East Portal. They were stocked at the boat ramp approximated 0.7 miles above the East Portal and the barrier.

Because electrofishing removal estimates are known to be biased low due to size selectivity and individual capture heterogeneity, we took several approaches to reduce this bias recommended by Riley and Fausch (1992) and Saunders et al. (2011). First efforts were made to use sufficient effort for high capture probabilities. Second, capture probabilities were modeled by fish species and length to account for heterogeneity. The data was analyzed in Program Mark with the Huggins Closed Capture Model (White and Burnham 1999, Huggins 1989). To reduce the bias associated with the size selectivity of electrofishing, capture probabilities were modeled with length as a covariate similar to the approach described in Saunders et al. 2011. Four models were built by estimating capture probabilities by length, species, species + length, as well as a constant capture probability for all fish. Model selection was done with AICc and population and parameter estimates were made by model averaging across all four models with AICc weights (Burnham and Anderson 2002). To estimate the total trout in the study reach in March 2013, the two pass removal estimate was expanded for the length of canal that contained similar habitat and added to the estimate for the stilling basin. The confidence intervals were calculated by summing the variances of each estimate (Delta Method) and multiplying by 1.96.

Four groups of fish were tagged and released in East Portal upstream from the Gunnison Tunnel to challenge the barrier. One hundred and twenty-five fish (59 brown trout and 66 rainbow trout) from the March 2013 sampling of the stilling basin were moved from below the barrier to above and received both coded wire tags and adipose fin clips. Mean length of the tagged fish was 241 mm for brown trout (range 165-310 mm) and 232 mm for rainbows (180-392 mm). Wild fish were captured by boat electrofishing on June 17 and 19, 2013, in the Gunnison River above the barrier and tagged with both coded wire tags and adipose clips. A total of 1,265 fish (653 rainbow trout and 612 brown trout) were tagged, the mean length of brown trout was 281 mm (103-737 mm) and 336 mm (82-547 mm) for rainbows. Fingerling rainbow trout from the Rifle Falls Fish Hatchery were also tagged and released into the Gunnison River in East Portal above the barrier. A total of 19,800 fish with a mean length of 68 mm were tagged with coded wire tags on June 24-26, 2013 and stocked into the Gunnison River 0.7 m above the barrier on July 26. Due to the results of the first study season, the focus in 2014 was on tagging larger fish and 1,841 wild fish from the Gunnison River above the barrier were tagged with 32 mm half duplex PIT tags. The mean length was 396 mm (200-545 mm) and an estimated 21.7% of the fish larger than 200 mm in the Gunnison River above the barrier were tagged. A total of 23,031 trout from 68mm to 737mm were tagged in the 2013-2014 and released in the Gunnison River above the barrier.

Mark recapture population estimates in the study reach were conducted in October 2011, October 2013, July 2014 and October 2014 with a 14 ft aluminum jet boat with Smith Root 2.5 GPP electrofisher. The study reach, equipment and methods for all occasions were the same. Fish were measured to the nearest millimeter and all fish on the recapture pass were weighed to the nearest gram. All captured fish were examined for fin clips and checked for coded wire tags with a Norwest Marine Technology T-Wand Detector and for PIT tags with an Oregon RFID handheld reader. On the marking pass all fish greater than 150 mm were marked with a caudal fin punch and held in a live pen to ensure recovery. Fish were returned by boat throughout the study reach to ensure redistribution in the population. The recapture pass was completed 72 hours after the marking pass and generally accepted methods were followed for mark recapture studies (Curry et al. 2009). The interval between capture events was chosen to maximize redistribution of marked fish throughout the population but to attempt to meet demographic and geographic closure assumptions of the model. The first power plant served as an upstream migration barrier further ensured geographic closure; block nets downstream were not feasible to the high volume of water in the canal (600-900 cfs). Model assumptions appear to have met well as marked fish were not observed to be encountered in any temporal or spatial pattern in the canal. Capture probabilities were good and the catch per unit effort of fish was similar between the passes.

A stationary PIT tag antenna was constructed above the penstock of the power plant but below the barrier in the spring of 2014. The objective was to differentiate fish deterred by the barrier and turbine mortality as well as increase detection of tagged fish. The antenna was operational for less than two months as the extreme velocities of the water (900 cfs in a 10.5 ft. wide concrete channel) made it impossible to keep in place. No tags other than test tags were detected by the antenna.

Fish population estimates were made with the Huggins Closed Capture Model in Program Mark (Huggins 1989, White and Burnham 1999). Four models were built by estimating capture probabilities by length, species, species + length, as well as a constant capture probability for all fish, identical to a Lincoln Petersen model (Seber 1982). Model selection was done with AICc and population and parameter estimates were made by model averaging across all four models with AICc weights (Burnham and Anderson 2002).

Figure 3. The electric fish barrier on the east portal of the South Canal.

RESULTS

The results of the population estimates are summarized in Table 1 and Figure 4. Length frequency histograms from the fall 2013 sampling are presented in Figures 5-7. Model selection results from are summarized in Appendix A, Tables 2-6.

The population modeling exercise in Program Mark provided good results and estimates appeared accurate (all years) and relatively precise (except for October 2011). The expected bias of population estimates should be low due to model assumptions being met, and the ability to model the size selectivity of electrofishing with fish length covariates. The top population model for the October 2011 data contained terms that varied capture probability by length and time while the second ranked model that contained terms for species, length and time was 2.40 ΔAICc units behind. Models with a term for fish length contained 0.98% of the model weights. Capture probabilities were lower during this survey (0.10) compared to subsequent surveys due to the higher flows and lower total number of fish captured.

In March 2013, the top population model for the canal and the stilling basin had a single capture probability for all fish regardless of species or length while the second ranked model contained a term for species. These two models are essentially identical to the simple Zippin two pass removal model and had 73.2% of the model weight (Zippin 1956). Although it has been shown that electrofishing surveys generally have a size related bias, this effect was not seen in these data because of how few fish were in the canal outside of the stilling basin and there was little variation in fish size compared to the fall surveys. Because of the low density of fish, moderate capture probabilities and similar sized fish, the data from the canal were too sparse to support more detailed models. There was no evidence of size selectivity in the stilling basin with the small mesh seine.

The top population model for the October 2013 data contained terms that varied capture probability by length, species and time while the second ranked model that contained terms for length and time. These two models accounted for 100% of the model weights and had much higher support than a simple Lincoln-Petersen (19-27 ΔAICc units behind). Capture probabilities were high (0.33) due to the lower flow conditions than 2011. Model selection uncertainty was taken into account in all surveys by model averaging across all four models with model weights to get parameter estimates and population estimates.

The significant increase (95% level) of total fish in the canal from April 2013 to October 2013 is evidence for fish successfully running the barrier and surviving the turbines. After the March estimate, when 876 fish were removed from the canal, the population estimate increased by 1,057 fish by October. The total number of estimated fish was significantly greater (at the 95% level) in October than in April and was not significantly different than in the October 2011, before the barrier. The size structure and species composition of the fish in the 2013 also provide evidence of fish entrainment, specifically for brown trout (Figures 5, 6 and 7).

Table 1. Fish Population Estimates and 95% Confidence Intervals from the South Canal 2011-2014. These estimates are for age 1 fish and older, the stocked CWT tagged rainbows are excluded from the rainbow trout estimates.

Date	Species	# Caught	Population Estimate in Study Reach
October 2011	Brown Trout	415	2,359±981
	Rainbow Trout	108	634±354
March 2013	Brown Trout	683	924±52
	Rainbow Trout	495	659±46
October 2013	Brown Trout	573	1,035±150
	Rainbow Trout	277	728±235
	Stocked CWT Rainbow	246	1,486±768
	CWT, Adipose Clipped Brown	2	NA
	CWT, Adipose Clipped Rainbow	0	NA
July 2014	Brown Trout	225	586±52
	Rainbow Trout	132	638±469
	Stocked CWT Rainbow	25	NA
	CWT, Adipose Clipped Brown	0	NA
	CWT, Adipose Clipped Rainbow	0	NA
Oct 2014	Brown Trout	305	964±258
	Rainbow Trout	277	936±278
	Stocked CWT Rainbow	15	NA
	CWT, Adipose Clipped Brown	0	NA
	CWT, Adipose Clipped Rainbow	4	NA

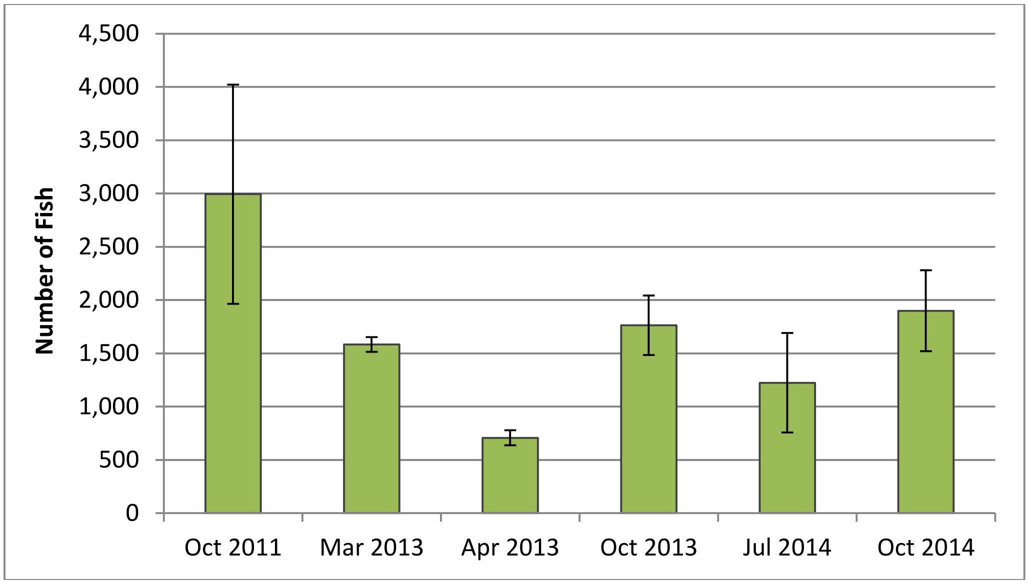

Figure 4. Estimated total number of trout age 1 and older and 95% confidence intervals in the South Canal study reach. After the March 2013 estimate, 876 fish were removed from the canal study reach and the barrier was operational at the start of the irrigation season in April 2013. There are about 1,094 fewer fish in the study reach since the barrier was installed but the decline is not significant at the 95% level, mostly because of the low capture probability and corresponding high uncertainty around the October 2011 estimate.

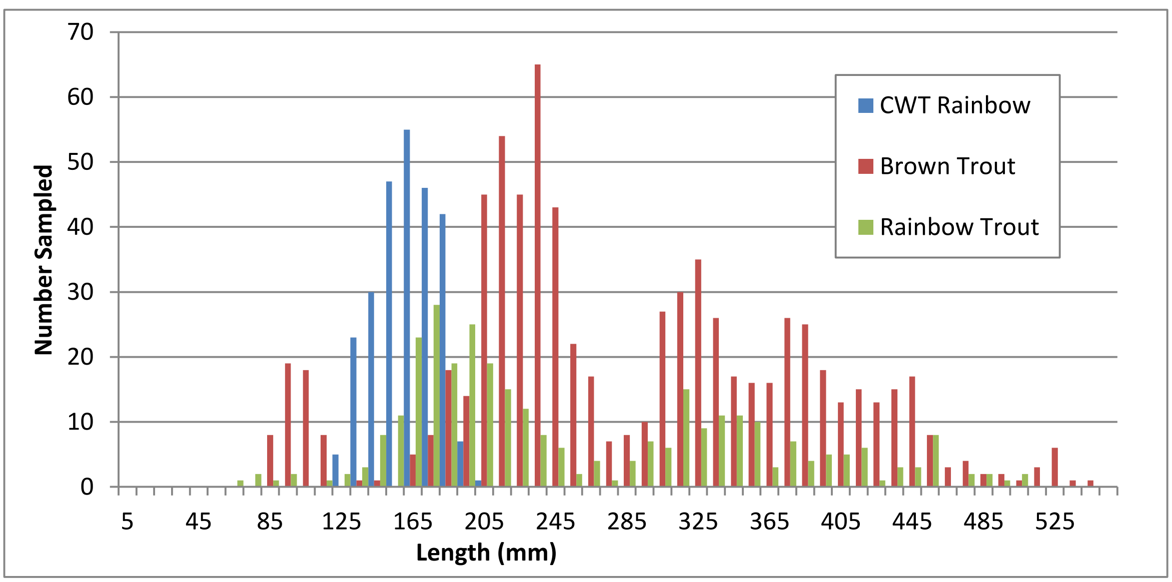

Figure 5. Length frequency histogram of trout captured in the South Canal in October 2013. A total of 246 coded wire tagged rainbows were captured that had been stocked upstream of the guidance system (plus 10 recaptures). They had a mean length of 163 mm (123-204). Two other coded wire tagged fish were captured, a 310 mm brown and 337 mm brown (the 310 mm fish was also recaptured). No tag loss was observed, all of the larger fish were double marked and no fish were observed with an adipose clip but without a CWT.

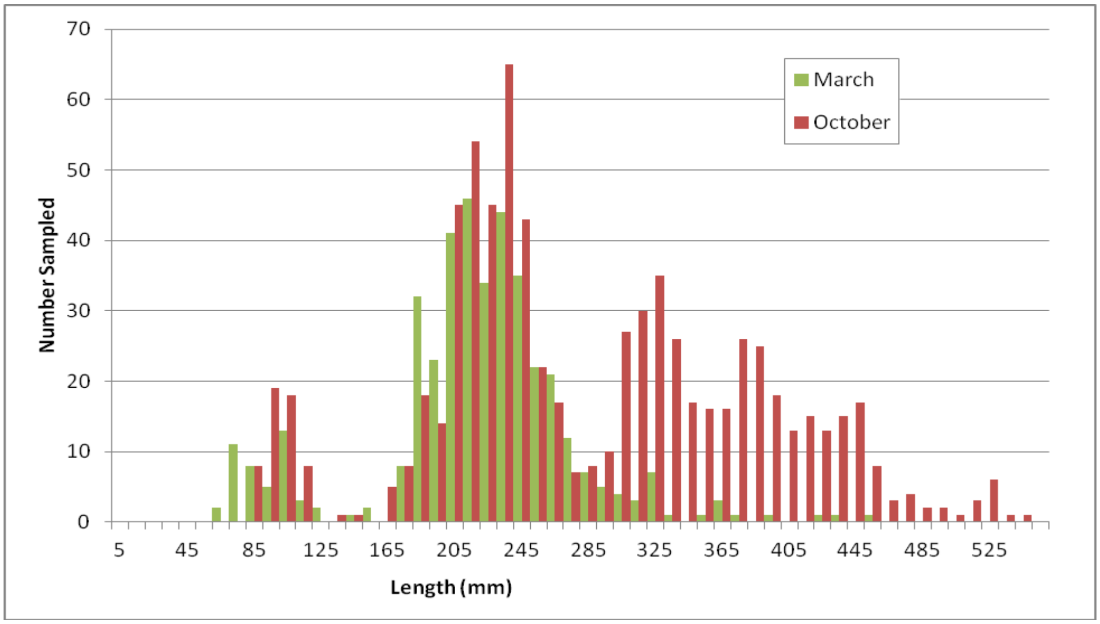

Figure 6. Length frequency histogram of brown trout captured in March and October 2013.

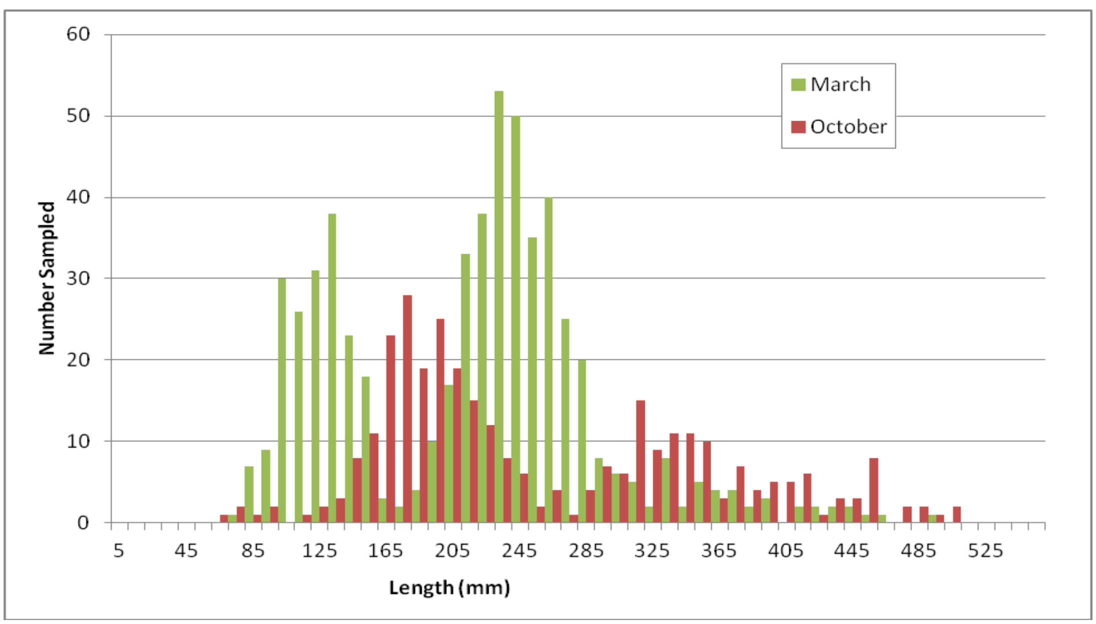

Figure 7. Length frequency histogram of rainbow trout captured in March and October 2013.

The top population models for the July and October 2014 data contained terms that varied capture probability by length, species and time. The top two models that included length accounted for 100% of the model weights. Capture probabilities were good in July (0.11-0.32) and (0.17-0.20) October. Model selection uncertainty was taken into account in all surveys by model averaging across all four models with model weights to get parameter estimates and population estimates.

The population modeling exercise for all the mark recapture data indicated that modeling capture probabilities by length was important under these conditions which agrees with previous work on the topic (Saunders et. al 2011). Using a simple Lincoln-Petersen model under these conditions could underestimate population size by overestimating the capture probability for small fish, even when using a length cutoff designed to exclude age 0 fish. Figure 8 shows an example of the estimated capture probability by length and Figure 9 shows a comparison of population estimates with and without the length covariate.

In October 2011, there were an estimated 2,994±1,043 fish in the South Canal study reach. In the spring of 2013 there were an estimated 1,583±70 in the study reach, 89% in the stilling basin. Eight hundred and seventy-six of these fish were removed from the study reach leaving an estimated 707 fish when the irrigation flows first began in the spring of 2013. In October 2013 the estimated population had increased to 1,764±279 trout. The population estimate of total fish in the study reach decreased from October 2011 to 2013 but that difference was not significant at the 95% level, likely due to the uncertainty around the 2011 estimate caused by lower capture probability likely due to higher flows. Subsequent sampling occasions had much higher capture probabilities generally in the 20% range (0.11-0.33). In 2014 the study reach contained 1,224±239 fish in July and 1,900±379 in October.

In 2013, a total of 248 coded wire tagged fish from 123 mm to 337 mm were documented passing through the barrier, mostly smaller stocked rainbow trout (n=246 mean length 163 mm in October). Only two larger wild brown trout were confirmed passing the barrier (310 and 337 mm). Of the tagged fish that were documented to have run the barrier in 2013, the stocked rainbows represent 1.24% of the fish marked in East Portal and the wild brown trout were 0.3%. Overall, 1.17% of all the tagged fish in East Portal were captured in the study reach in 2013. In the 0.72-mile study reach there was an estimated 1,486±768 coded wire tagged rainbows or 7.5% of the tagged fish in East Portal.

These results do not represent a direct estimate of entrainment rates as only 9.4% of the total length of the canal was sampled at a single time interval. Rather, the results represent the number of entrained fish in the study area that were detected. It should be interpreted as a minimum number of fish that navigated the barrier because fish would have to pass the through the guidance system, travel the 5.7-mile-long tunnel, avoid entrainment in two small lateral canals, survive passage through the hydropower turbines and remain in the first 0.72 miles of the 7.7-mile canal to be detected. If the density of fish in the study reach is representative of the rest of the canal, then an estimated 15,809 coded wire tagged rainbow fingerlings would have been entrained or 79.8% of those fish and 3.2% of the larger marked wild brown trout in 2013. This is most likely an over estimate of entrained fish because the study reach could have a higher density of fish than the other reaches of the canal, but it demonstrates the same trend of high entrainment rates for small fish and relatively low rates for larger fish and can be interpreted as a potential maximum number. While estimating robust entrainment rates with the barrier is not possible in this study, the true rates are likely between these minimum and maximum values; 8-80% for small rainbow trout and 0.3-3.2% for larger brown trout.

In 2014, a total of 44 tagged fish were encountered, 40 of the hatchery rainbows (mean length 326 mm at the time of capture). Four CWT and fin clipped wild rainbow trout (296-398 mm) were found. It is unknown exactly when or what size all the tagged fish in 2014 passed the barrier because fish lived and grew in the canal throughout the study. The 2013 data give the best idea of size of fish that ran the barrier because they were in the canal for a maximum of seven months. The large number of CWT tagged rainbows could have passed the barrier as small as 68 mm and then survived to be captured at a larger size.

By the end of the study 288 small or medium sized fish had been documented passing the barrier. Only four fish >300 mm, and no fish >400 mm were documented passing the guidance system. Only 1.3% of all tagged fish were recovered in the canal study reach in two years. While turbine mortality and fish excluded from the study reach by the trash racks on the penstock cannot be differentiated from fish excluded by the barrier, very few large fish have been observed passing these barriers. The number of large fish (>350mm) in the study is not significantly different after the barrier (Figure 10) even though there is no evidence that fish of that size are passing through in great numbers. Large numbers of smaller fish have been shown to run the barrier as evidenced by both the number of marked fish and the stable trout population in the canal even after the barrier was in use. The lack of a decline in fish populations in the canal after the barrier is likely related to higher than expected survival and growth of small fish entrained in the canal.

In July 2014, 17% of the fish captured during the population estimate (37% greater than 350 mm) had been handled the previous October by the presence of a healed caudal punch scar. This indicates that there is fair to good over winter survival in the canal. Growth of fish that live in the study reach is also relatively high; coded wire tagged rainbows grew an average of 6.4 inches from age 1 to age 2. With the good annual survival and growth rates, the large numbers of smaller fish that pass the barrier maintain a relatively stable population of fish in the study reach, even though large fish do appear to be excluded from the canal by the electric barrier.

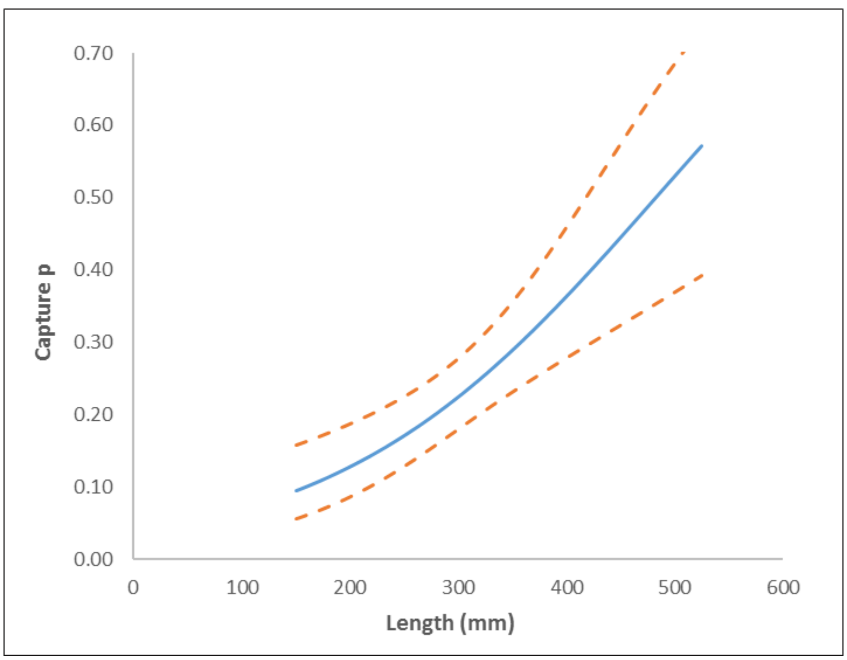

Figure 8. Estimated capture probability by length and 95% confidence interval (dashed lines) for trout in the South Canal in October 2014.

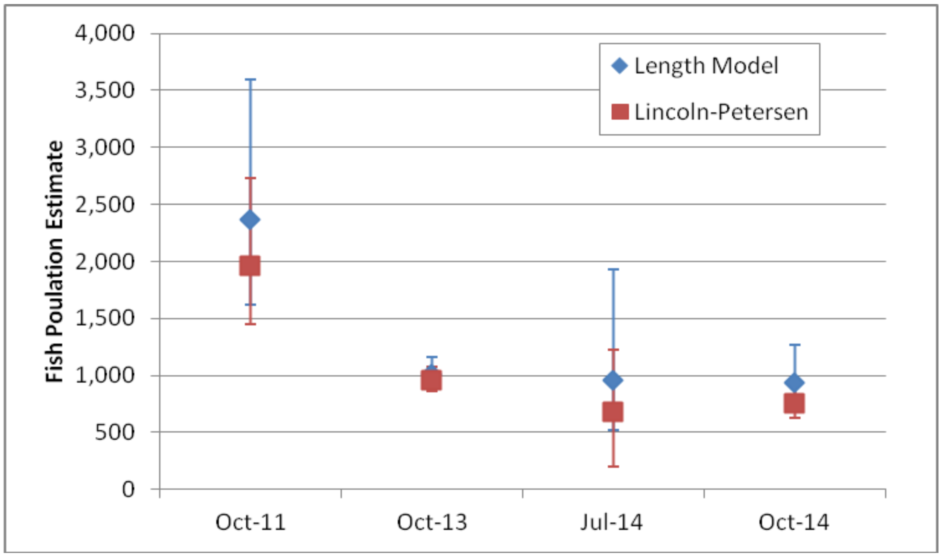

Figure 9. Brown trout population estimates from the Huggins Closed Capture model in Program Mark comparing models with a fish length covariate to a standard Lincoln-Petersen. The estimates that used length to model capture probabilities were on aver 23% higher (6-41%) than the Lincoln-Petersen. Models containing length as a covariate had between 98-100% of the model weight across all mark recapture sampling occasions.

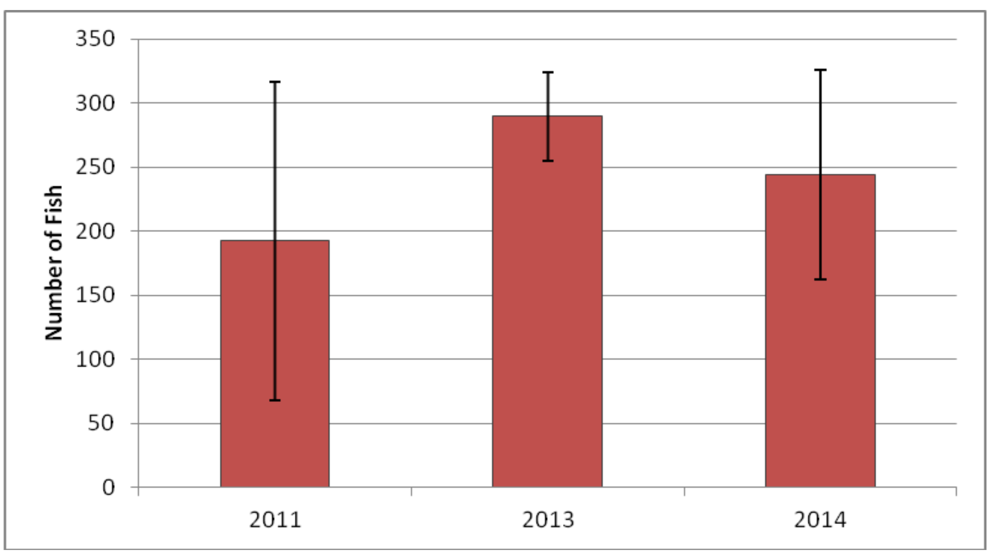

Figure 10. Estimated total number of trout greater than 350 mm in the South Canal study reach in the October sampling periods. While very few (4) fish greater than 300 mm have been documented passing the barrier and turbines, growth and survival of smaller entrained fish supports a stable number of larger fish in the study reach.

DISCUSSION AND MANAGEMENT RECOMMENDATIONS

The South Canal contained approximately 1,094 fewer fish in October 2014 after the barrier, than in October 2011. While the total fish estimates in the canal have declined since the barrier was installed, there is not a significant difference at the 95% level mostly due to the low capture probability (0.8-0.12) and corresponding high uncertainty around the October 2011 estimate. The number of brown trout only is significantly lower at the 95% level in 2014 (two years after the barrier was installed) while the number of rainbow trout has remained relatively stable (Figure 11).

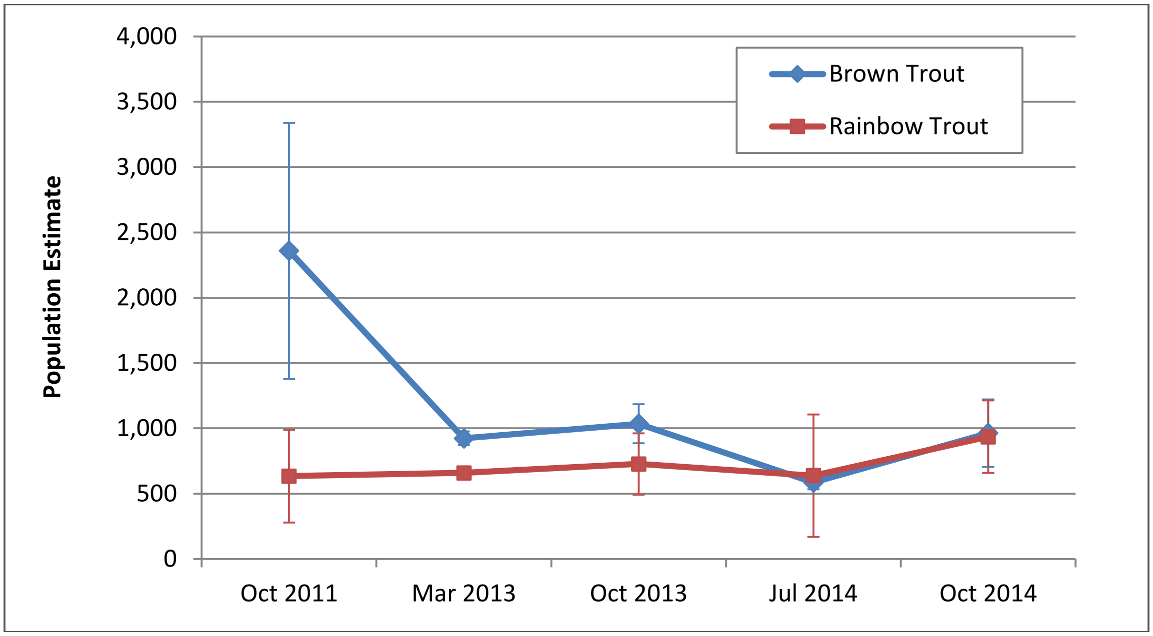

Figure 11. Population estimates of rainbow and brown trout and 95% confidence intervals for the South Canal Study reach 2011-2014. There were signifcantly fewer brown trout in 2014, two years after the installation of barrier. Rainbow trout numbers have raimained relatively stable.

Of the 23,031 tagged fish, only 1.3% were recovered in the canal study reach in two years. At the end of the study, 288 small or medium sized fish had been documented passing the barrier. Four fish greater than 300 mm and no fish greater than 400 mm were documented passing the barrier. This size selectivity is expected with electrically based barriers and electrofishing is known to be highly size selective as well (Saunders et. al 2011). It is also likely that turbine mortality is higher on larger fish, further selecting for smaller fish to make it into the study reach. The growth and survival of fish in the canal is higher than expected as evidenced by the high proportion of recaptured fish from October 2013 to July 2014. The practice of running 100 cfs into the canal twice a month in the winter and relatively mild recent winters apparently allowed for good fish survival during the winter of 2013-2014.

Fish in the Gunnison River are successfully passing the electric barrier and surviving the turbines, but mostly smaller fish. Their growth and survival in the canal maintains a stable fish population that is lower than before the barrier, significantly (at the 95% level) for brown trout only. The difference between species is likely due to two factors; larger size of age 0 brown trout and potential spawning of rainbow trout in the study reach. Because brown trout emerge about 8-10 weeks earlier than rainbow trout they are larger during their first summer. Because the barrier is size selective, brown trout fry are expected to be entrained at a lower rate than rainbows. The canal is first filled with water around April 1st of each year, just before rainbow trout spawn. Large numbers of age 0 rainbow trout were observed in the canal in July 2014 (they were smaller than the 150 mm size cut off used in the fish population estimates). It is unknown if they were entrained fish from the Gunnison River or were spawned in the canal, both are likely. Brown trout spawn in October in the Gunnison River and flows are generally shut off in the canal around October 31. Water flow is then stagnant or 100 cfs (twice a month for 24 hours) in the canal in winter. There is very little spawning habitat for brown trout in the canal and it is variable and poor quality compared to rainbow trout, which spawn at higher flows that are stable or increasing. A combination of higher entrainment rates and better potential spawning success in the canal likely leads to higher number of small rainbow trout in the canal.

If the barrier is successfully excluding many of the fish greater than 300 mm and most of the fish greater than 400 mm, then it is excluding approximately 15% of the trout greater than 150 mm and 26-71% of sexually mature fish based on 2013 data on the Gunnison River. Low numbers of age 2 fish in the Gunnison are sexually mature (mostly males) while most age 3 fish are mature (E. Gardunio, Colorado Parks and Wildlife, unpublished data). So while the barrier is generally meeting its stated objective, it's not protecting all of the sexually mature fish. Excluding higher proportion of small trout from downstream passage is likely to be difficult and will be dependent on several factors including the voltage gradient of the barrier and the approach velocities of the water at the barrier. Excluding a larger proportion of adult fish than is currently occurring is a more reasonable expectation for the East Portal barrier with some operational changes.

As approach velocities increase above 2.5 fps the probability of excluding small salmonids with an electric barrier decreases (Demko et al. 1994, Pugh et al. 1970). The approach velocities at the South Canal barrier varied between 0.7 and 2.3 fps in October 2011 when the tunnel was flowing about 730 cfs and the river below the tunnel was about 580 cfs. Under those flows, better deterrence of small trout should be possible with operational adjustments, but more work is needed to determine approach velocities at various flows. The field strength of the South Canal barrier is currently about 1v/inch or 0.4v/cm (Smith Root 2011) which is relatively conservative compared to other barriers designs. Most other downstream oriented barriers are graduate-field fish barriers (GFFB) where several rows of electrodes produce increasing voltage gradients between 0.2-1.2 v/cm while other designs have utilized voltage gradients as high as 3.0 v/cm (Raymond 1956, Burger et al. 2015). The GFFB technology appears more effective in deterring downstream movement of fish but was not applied at the South Canal due to site specific conditions. Diverting downstream moving fish is one of the more difficult applications of electric fish barriers (Burger et al. 2012). Achieving complete deterrence of all fish is unlikely in scenarios like East Portal. The objective there should be to reduce the amount of entrainment much as feasible within the constraints of the system. More work is necessary to determine if increasing the voltage gradient, or other operational changes at the East Portal barrier could improve performance on smaller fish.

The electric fish barrier on the South Canal of the Gunnison River appears to effectively exclude large fish from the south canal, resulting in fewer entrained fish from the river. Fish populations in the South canal, while lower than before the barrier, appear stable due to the number of entrained smaller fish, potential spawning of rainbow trout and better than expected growth and survival of fish in the canal. The electric barrier on the South Canal should continue to be operated whenever feasible during the irrigation season and future study is needed to examine if operational changes of the current barrier can increase the probability of excluding more adult fish.

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Appendix A. Model Selection Results for Population Estimation Models

Table 2. Model Selection Results for the Mark Recapture Electrofishing in October 2011. Population estimates and capture probabilities were calculated by model averaging across all four models using model weights. The "Time" and "Time+Species" models are identical to the standard Lincoln Petersen model.

Model	AICc	Number of Parameters	Delta AICc	AICc Weights	Model Likelihood
Time+Length	893.0038	3	0	0.75	1.00
Time+Species+Length	895.4048	5	2.40	0.23	0.30
Time	900.3091	2	7.31	0.02	0.03
Time+Species	902.7106	4	9.71	0.01	0.01

Table 3. Model Selection results for the Two Pass Removal Electrofishing in March 2013. Population estimates and capture probabilities were calculated by model averaging across all four models using model weights.

Model	AICc	Number of Parameters	Delta AICc	AICc Weights	Model Likelihood
Constant p	117.40	1	0	0.528	1.00
Species	119.30	2	1.90	0.204	0.39
Length	119.39	2	2.00	0.195	0.37
Length+Species	121.34	3	3.94	0.073	0.14

Table 4. Model Selection Results for the Mark Recapture Electrofishing in October 2013. Population estimates and capture probabilities were calculated by model averaging across all four models using model weights. The "Time" and "Time+Species" models are identical to the standard Lincoln Petersen model.

Model	AICc	Number of Parameters	Delta AICc	AICc Weights	Model Likelihood
Time+Species+Length	1760.461	5	0	0.77	1.00
Time+Length	1762.837	3	2.38	0.23	0.30
Time+Species	1779.036	4	18.58	0.00	0.00
Time	1787.185	2	26.72	0.00	0.00

Table 5. Model Selection Results for the Mark Recapture Electrofishing in July 2014. Population estimates and capture probabilities were calculated by model averaging across all four models using model weights. The "Time" and "Time+Species" models are identical to the standard Lincoln Petersen model.

Model	AICc	Number of Parameters	Delta AICc	AICc Weights	Model Likelihood
Time+Species+Length	663.08	5	0	0.802	1
Time+Length	665.88	3	2.80	0.198	0.2469
Time+Species	685.91	4	22.83	0.000	0
Time	693.13	2	30.05	0.000	0

Table 6. Model Selection Results for the Mark Recapture Electrofishing in October 2014. Population estimates and capture probabilities were calculated by model averaging across all four models using model weights. The "Time" and "Time+Species" models are identical to the standard Lincoln Petersen model.

Model	AICc	Number of Parameters	Delta AICc	AICc Weights	Model Likelihood
Time+Length	1106.96	3	0	0.876	1.000
Time+Species+Length	1110.87	5	3.9097	0.124	0.142
Time	1122.71	2	15.7451	0.000	0.000
Time+Species	1126.72	4	19.7574	0.000	0.000