An assessment of limiting factors and management alternatives for the Beaverhead River tailwater trout fishery

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Introduction

The Beaverhead River tailwater can provide a trout fishery unique in both abundance and average size of fish; however, both characteristics of the fishery have fluctuated through time. Reservoir releases, particularly during discrete periods of drought, have been implicated as a limiting factor for large brown trout (Oswald 2009). Although stochastic input of sediment from Clark Canyon Creek during periods of low discharge also appears to have a negative effect on the trout population, formal assessment of mechanisms (e.g., direct mortality or displacement) and its influence has not occurred. Finally, it is unclear how inter and intraspecific interactions influence abundance and size of Beaverhead River trout. While some general management targets have been formalized (i.e., instream flow reservations of 200 cfs, Bureau of Reclamation Drought Plan) no population-specific management goals have been established for the Beaverhead River, thereby reducing the benefit of understanding population drivers. However, a 50-year dataset that has not been comprehensively analyzed is available to help guide management of this fishery. The purpose of this report is to define management goals, evaluate factors that limit the Brown and Rainbow Trout populations, and identify actions that are expected to result in the most effective and efficient attainment of management goals for the Beaverhead River tailwater fishery.

Study Area

The Beaverhead River originates at Clark Canyon Dam, which impounds the Horse Prairie and Red Rock watersheds in southwestern Montana. The Beaverhead River flows about 120 kilometers until it meets the Big Hole River downstream of Twin Bridges, MT to form the Jefferson River. The establishment of Clark Canyon Reservoir, which is primarily used for irrigation, converted the upper 25.7 km (Clark Canyon Dam to Barrett's Diversion) of the Beaverhead River into a tailwater fishery in 1964. The fishery annually supports up to 48,500 angler days, which results in over $21,000,000 of direct expenditures. The trout population in the tailwater reach is characterized by the Hildreth study section, which is about 1905 meters long and was established in 1966 (Figure 1).

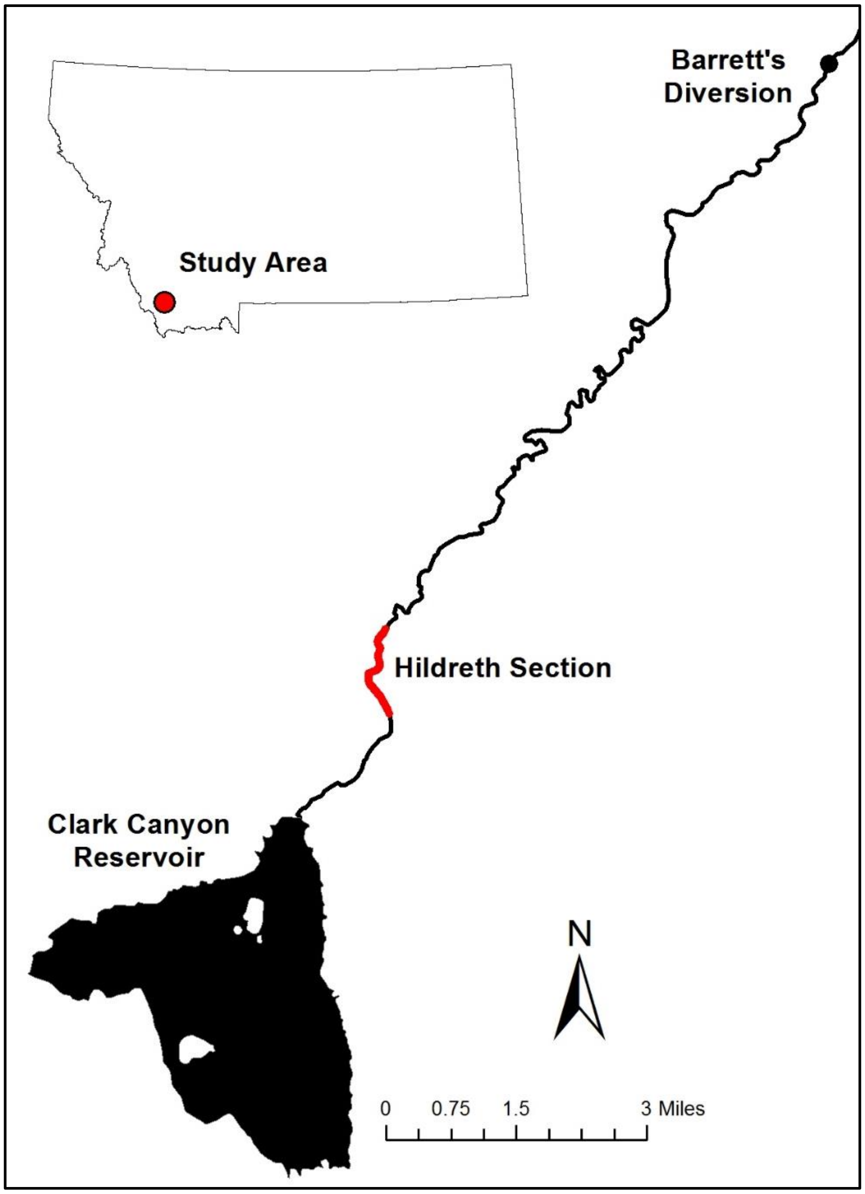

Figure 1. The Beaverhead River tailwater and study section.

Methods

The fisheries data analyzed in this report were collected over 50 years from the Hildreth section of the Beaverhead River during spring mark-recapture abundance surveys. Trout were collected by mobile anode electrofishing each March or April during single pass marking and recapture runs 7 to 14 days apart (Vincent 1971). All captured trout >203 mm were measured to the nearest mm or tenth of an inch and weighted to the nearest gram or hundredth of a pound. The study section and data collection methods are described in more detail by Oswald (2009). Trophy fish were defined (i.e., >460 mm) using the proportional size distribution designation for "Trophy" lotic Brown Trout (Zale et al. 2012). Response variables (length-specific Chapman closed population abundance estimates) and covariates (biomass, relative weight, abundance estimates) were generated and standardized to stream mile for Brown and Rainbow Trout using a R-based proprietary FWP fisheries database and analysis tool. All other statistical analyses (i.e., regression models) were completed using Minitab software.

Management Goal Development

To define management goals we examined historical data to determine averages of trophy (>460 mm) and total (>203 mm) trout per mile of stream. Adopting long-term averages as goals, or "managing for history," is often not a preferred approach because active evaluation and implementation of management actions that optimize desirable attributes of a fishery may not occur; management goals can simply be attained as the most likely outcome under the historic management regime. However, the recent history of the Beaverhead River makes exploration of this approach warranted. Since 1988 Beaverhead River hydrology has been affected by drought conditions that cause a statistically significant downward trend in overwinter and irrigation season releases over the life of Clark Canyon Dam (Figure 2). This extended period of drought has been characterized by 5- to 10-year periods of very low winter releases interspersed with 3- to 4-year periods of above average winter releases, thereby creating a boom and bust fishery (Oswald 2009). If this 28 year-long pattern continues then seeking reservoir management options that stabilize variability in hydrology and the fishery by regressing to mean conditions may be favorable.

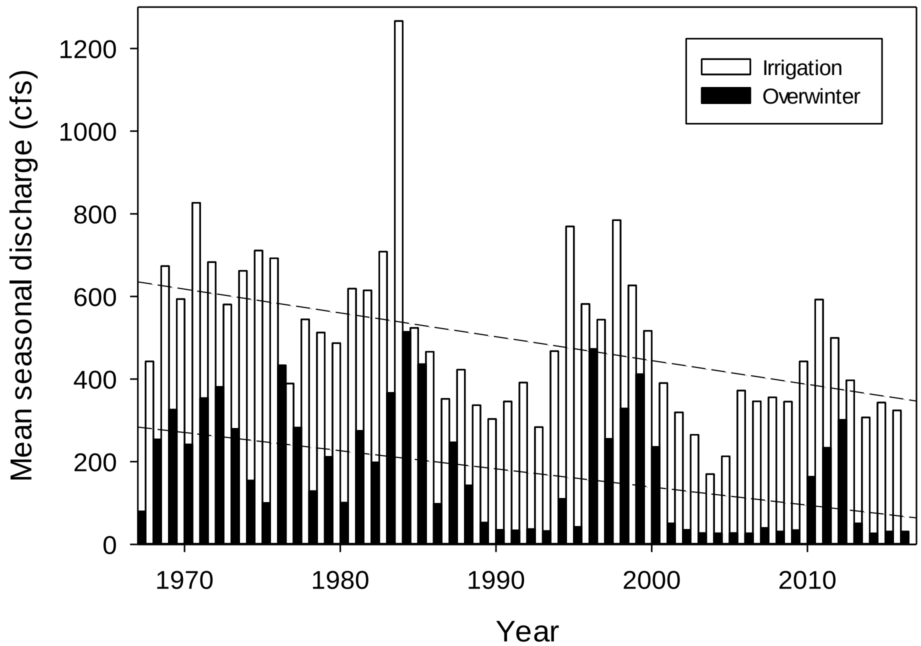

Figure 2. Mean overwinter (November 1st-March 31st) and irrigation (April 1st-October 31st) season discharge releases from Clark Canyon Dam to the Beaverhead River. Dashed lines are regressions between discharge and year for overwinter (P=0.003; R^2=18.5%) and irrigation (P=0.006; R^2=16.5%) seasons.

Management Action Evaluation

We identified possible management actions by evaluating hypotheses related to three potential limiting factors (discharge, sediment events, and carrying capacity) to determine which were most influential to attainment of population goals. Limiting factors were evaluated in the context of outcomes that can be theoretically influenced through management actions (i.e., changing angling regulations, optimizing discharge regime from Clark Canyon Dam, etc.). For each management goal a set of candidate models was developed for each limiting factor using covariates that could serve as management targets and response variables that related directly back to the management goal (Table 1). For each limiting factor, we selected covariates based on *a prioi* hypotheses about their effect on Beaverhead River trout populations and individually assessed them using simple linear regression models. Next, one model was developed for each limiting factor by including covariates that produced statistically significant univariate models (α < 0.05) in a stepwise procedure (α < 0.15 to enter or remove). Covariates from statistically significant univariate models that did not follow the relationship predicted by *a prioi* hypotheses were not included in the multivariate limiting factor models. In instances where we suspected a covariate explained variation attributable to another limiting factor we included the covariate(s) from that limiting factor model in all stepwise comparisons. Finally, a single model for each management goal was developed by comparing Mallows Cp and S among all possible combinations of covariates from each limiting factor model using a best subsets regression to develop a single model for each management goal. We took this approach to maximize our understanding of how each potential limiting factor affects the trout population, set clear thresholds for influential covariates, and ultimately determine how we can most efficiently achieve management goals.

Table 1. Management goals, response variables, and limiting factors for the Beaverhead River trout population.

<table>
<tr><th>Management Goal</th><th>Response variable</th><th>Potential Limiting Factors and Covariates</th></tr>
<tr><td>20% of Brown Trout are >460mm</td><td>Brown Trout >460 mm / Brown Trout >203 mm per mile</td><td rowspan="4">Discharge
- overwinter
- irrigation season
- habitat maintenance
Sediment Events
- discharge in Clark Canyon Creek relative to the Beaverhead River
Carrying Capacity
- Biomass
- Condition
- Other sizes or species of trout</td></tr>
<tr><td>1600 Brown Trout per mile</td><td>Brown Trout > 203mm per mile</td></tr>
<tr><td>35% of Rainbow Trout are >460 mm</td><td>Rainbow Trout >460 mm / Rainbow Trout >203 mm per mile</td></tr>
<tr><td>600 Rainbow Trout per mile</td><td>Rainbow Trout > 203mm per mile</td></tr>
</table>

We evaluated hypothesized limiting factors related to overwinter, irrigation, and habitat maintenance discharges. Discharge regime has been previously described to limit the Beaverhead River trout population (Oswald 2009). The effect of overwinter discharge was evaluated for the winter prior to each sampling event (t) and over the theoretical lifetime of a 460-mm fish, which would be about 4 years (Jaeger, unpublished data). The lifetime model for brown trout considered the average discharge over the five previous winters, which encompass the period a fish captured at time t would have been an egg in the gravel (t-4) until it reached 460-mm and is indicative of overwinter conditions throughout its lifetime. The lifetime model for Rainbow Trout considered the previous six winters because the population >460 mm was typically comprised of more older age classes than with Brown Trout; we selected a timescale that would encompass lifetime conditions of four and five-year-old Rainbow Trout, including the season when they were embryos. Irrigation season discharges were similarly evaluated to include the year prior to sampling (t-1) and the average of irrigation season releases over the lifetime of a 460-mm fish captured at time t (t-4 to t-1). When evaluating abundance of trout >203 mm we also included lifetime discharge covariates from year t to t-2 because most of the respective populations are expected to be 2 or 3 years old. Finally, habitat maintenance models evaluated the effect of discharges hypothesized to mobilize most Beaverhead River substrate and reduce fine sediment in riffles (>600 cfs; BOR 2010), thereby improving spawning habitat and overall aquatic health. Habitat maintenance flows for a given year were described by the number of days discharge was >600 cfs. The effect of habitat maintenance flows on spawning habitat quality (t-5) and overall habitat quality for the year prior to sampling (t-1) and over the lifetime (t-4 to t-1) of a 460-mm fish captured in year t were evaluated. Because Rainbow Trout are spring spawners whose embryos may still be in redds when irrigation releases that can mobilize spawning substrates commence we also considered the difference between March and May discharges in years t-4 and t-5 to determine if redd scouring negatively affects future populations of Rainbow Trout.

The effect of sediment events originating from Clark Canyon Creek was assessed using covariates that compared peak annual discharge in Clark Canyon Creek with concurrent Beaverhead River discharges. Boyd (2014) described the convergence of events likely to result in a sediment event, while acknowledging there was uncertainty in their prediction. The first covariate defined a sediment event to occur when Clark Canyon Creek peak discharge was >30 cfs and concurrent Beaverhead River discharge was <300 cfs (Boyd 2014). We also evaluated Clark Canyon Creek peak discharges of >30 cfs when concurrent Beaverhead River discharge was <600 cfs, since that Beaverhead River discharge was anticipated to move and re-sort most substrates (BOR 2010). Because sediment events are ostensibly rare occurrences we used Clark Canyon Creek discharges generated by the five-year storm (82 cfs) coinciding with Beaverhead River discharges >600 cfs as defining criteria (Boyd 2014). Finally, we used a threshold of Clark Canyon Creek discharge being over 25% of concurrent Beaverhead River discharge to define sediment events. Because potential sediment events frequently occurred following population sampling in a given year, all evaluated covariates described both whether a sediment event occurred during the year prior to sampling (t-1) and the year of sampling prior to our surveys (t).

Carrying capacity was evaluated from the context that systemic productivity is fixed (i.e., biomass does not vary with the other two hypothesized limiting factors or time) and that fisheries management goals can be achieved by manipulation of trout population structure. We considered trout biomass, relative weight, and density to assess whether carrying capacity influences trout populations. We selected biomass as a predictor because we expected that as maximum capacity (i.e., kilograms of fish per mile) is approached the growth, condition, and survival of older fish will decrease and they will comprise a smaller proportion of the fishery. Similarly, we anticipated that average body condition (i.e., relative weight) would decrease as carry capacity is approached. As in previous models, we examined the influence of each covariate at the time of sampling (t) and cumulatively throughout the lifetime (t to t-3) of a fish

>460 mm at time t. Finally, we included number of fish <460 mm because we expected that if their abundance was high at a given carrying capacity the proportion of fish >460 mm would be low for the same reasons described for biomass.

In instances where the aforementioned covariates were poor predictors we also considered year as a covariate to assess whether long-term trend better characterizes the population than the hypothesized limiting factors.

Results

Management Goal Development

On average, there were about 315 Brown Trout >460 mm and 1610 Brown Trout >203 mm per mile, which equates to about 20% of the fishery being comprised of trophy fish (Figure 3). There were averages of about 225 Rainbow Trout >460 mm and 670 Rainbow Trout >203 mm per mile, which results in about 35% of the population being comprised of trophy fish (Figure 4). However, the average number of Rainbow Trout >203 mm was disproportionately skewed by two estimates from 1975 and 1976, which were omitted and reduced the long-term average to about 600 fish per mile. Therefore, our management goals for the Beaverhead River tailwater fishery are to:

1) Maintain a trophy fishery where at least 20% of brown trout and 35% of rainbow trout are >460 mm.
2) Maintain at least 1600 brown trout and 600 rainbow trout >203 mm per mile.

There have been over 1600 Brown Trout per mile in the population in most of the past 20 years; however, less than 20% were greater than 460 mm for the past 12 years (Figure 5). There have been fewer than 600 Rainbow Trout >203 mm three times in the past 12 years, although over 35% were >460 mm only once (Figure 6). Thus, our goal to maintain trophy Brown and Rainbow trout fisheries have not been met for over a decade.

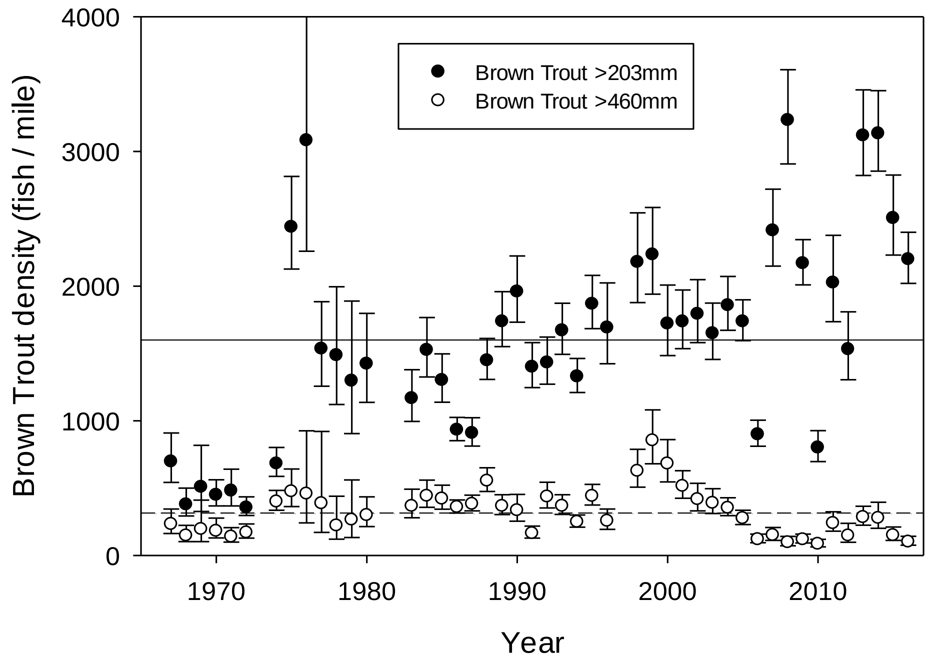

Figure 3. Density of Brown Trout >203 mm and >460 mm in the Beaverhead River. Mean density for Brown Trout >203 mm is shown by the solid and >406 mm by the dashed line.

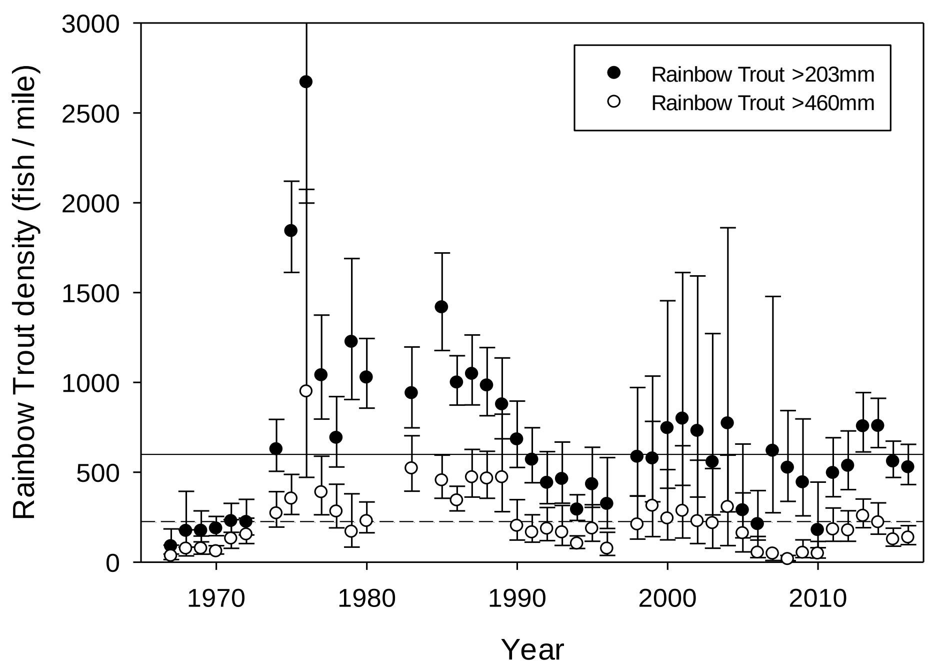

Figure 4. Density of Rainbow Trout >203 mm and >460 mm in the Beaverhead River. Mean density for Rainbow Trout >203 mm is shown by the solid and >406 mm by the dashed line.

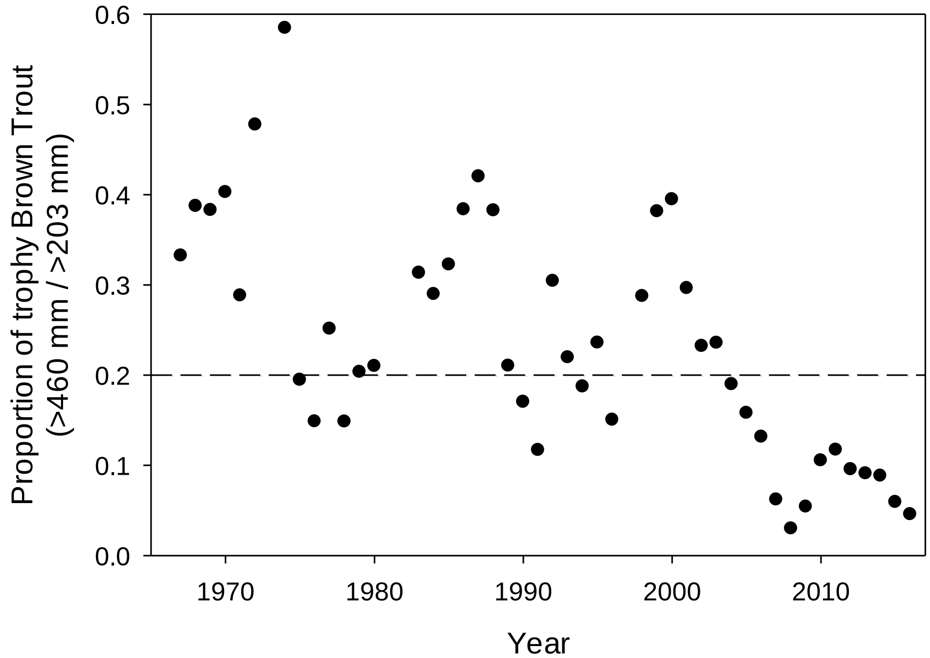

Figure 5. Mean proportion of Brown Trout >460 mm in the Beaverhead River.

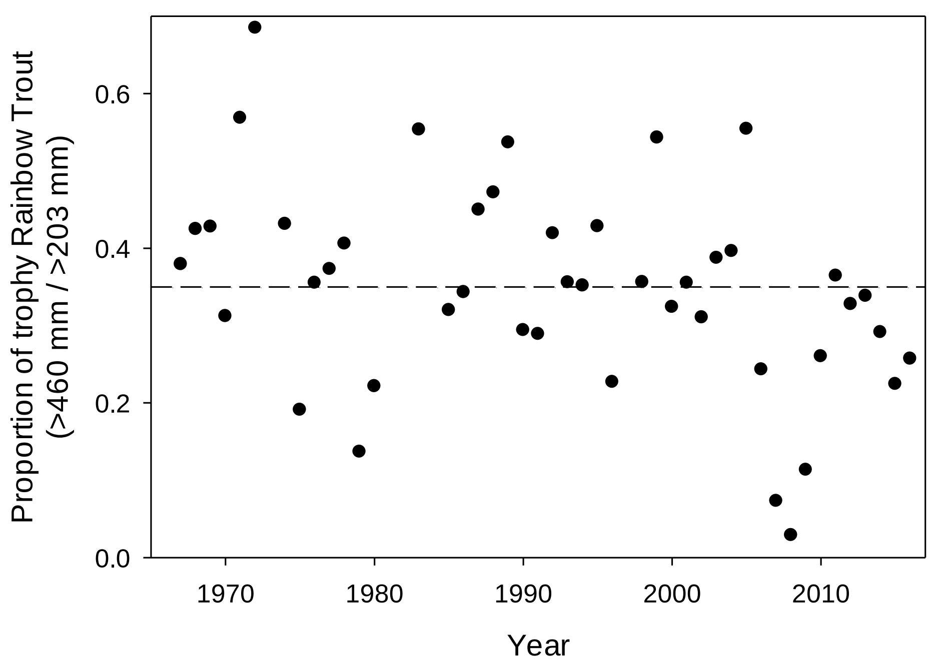

Figure 6. Mean proportion of Rainbow Trout >460 mm in the Beaverhead River.

Proportion of Brown trout >460 mm

Discharge had a significant positive effect on the proportion of trophy brown trout. Each model resulted in a statistically significant regression ($P < 0.05$), except for the model that assessed spawning habitat quality (Table 2). However, all evaluated covariates were significantly correlated with one another (i.e., during good water years overwinter discharge, irrigation discharge, and number of days > 600 cfs will all be relatively large). Lifetime overwinter discharge was the only covariate retained by the stepwise procedure; therefore, mean overwinter discharge from time t to t-4 was the only variable used in subsequent models used to determine population drivers.

Table 2. Factors limiting the proportion of Brown Trout >460mm related to discharge regime in the Beaverhead River.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Discharge (winter)	Minimum discharge from November 1st to March 31st	Positive	Positive	0.007	15.6%
Discharge (winter)	Mean discharge from November 1st to March 31st	Positive	Positive	0.005	16.6%
Discharge (winter)	Mean discharge from November 1st to March 31st from year t to t-4	Positive	Positive	0.000	51.2%
Discharge (irrigation)	Mean discharge from April 1st to October 31st in year t-1	Positive	Positive	0.006	16.5%
Discharge (irrigation)	Mean discharge from April 1st to October 31st from year t-1 to t-4	Positive	Positive	0.000	46.7%
Discharge (habitat)	Days with discharge >600 cfs in year t-5	Positive	None	0.105	--
Discharge (habitat)	Days with discharge >600 cfs in year t-1	Positive	Positive	0.001	22.5%
Discharge (habitat)	Mean days per year with discharge >600 cfs from year t-1 to t-4	Positive	Positive	0.000	50.7%

Sediment events affect the proportion of Brown Trout >460 mm. All evaluated covariates produced statistically significant regression models that explained 9% to almost 20% of the variation in proportion of trophy trout (Table 3). Sediment events are more likely to occur during low Beaverhead River discharges, which creates the possibility that the sediment event covariates we evaluated are redundant with discharge covariates (e.g., mean winter discharge from year t to t-4). To determine which, if any, sediment event covariates should be used in subsequent models we included all sediment event covariates with the discharge covariate in the stepwise procedure. Clark Canyon Creek discharges >82 cfs coinciding with Beaverhead River discharges >600 cfs was the only sediment event covariate included with the discharge covariate and will be hereafter used to define sediment events in subsequent models.

Table 3. Factors limiting the proportion of Brown Trout >460mm related to occurrence of a sediment event originating from Clark Canyon Creek.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q >300 cfs) in year t-1	Negative	Negative	0.039	9.3%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <600 cfs) in year t-1	Negative	Negative	0.014	12.9%
Sediment Event	Sediment event (CC Q >80 cfs &BVHD Q <600 cfs) in year t-1	Negative	Negative	0.012	13.4%
Sediment Event	Sediment event (CC Q / BVHD Q >25%) in year t-1	Negative	Negative	0.002	19.6%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <300 cfs) in year t	Negative	None	0.078	6.9%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <600 cfs) in year t	Negative	None	0.078	6.9%
Sediment Event	Sediment event (CC Q >80 cfs &BVHD Q <600 cfs) in year t	Negative	None	0.282	--
Sediment Event	Sediment event (CC Q / BVHD Q >25%) in year t	Negative	None	0.093	6.3%

Biomass, relative weight, and density of Brown Trout <460mm affect the proportion of Brown Trout >460 mm. All covariates produced statistically significant regression models; however, Brown Trout <460 mm explained about 59% of the variation in proportion of trophy fish while the remaining covariates explained 10 to 15% (Table 4). The relationship between relative weight covariates and the response was different than hypothesized. It was expected that relative weight would have asymptotic relationship where proportion of Brown Trout >460 mm would initially increase as relative weight increased then change relatively little. Data transformations (reciprocal, log) and quadradic models were explored to create an asymptotic model but had limited improvement over linear models. Moreover, linear models were preferred when comparing among models using Mallows Cp. It is possible that these relationships are linear, appear linear because we have not yet approached an asymptote in their respective values, or that other factors (i.e., overwinter discharge, sediment events) contribute more to variation in proportion of trophy brown trout than relative weight. Regardless, we used linear models for these covariates. All covariates except for relative weight were included in the stepwise regression model and all except relative weight from year t to t-3 were retained; however, the relationships between biomass and proportion of Brown Trout changed when included in a model with density of Brown Trout >460 mm. Both were negatively correlated with proportion of trophy Brown Trout when modeled individually but biomass covariates (kg/mi) were positively correlated with proportion of trophy Brown Trout when included in a model with population density (fish/mile). We hypothesize this model is simply predicting that as average fish weight increases the proportion of trophy fish increases which we know to be true by definition and isn't related to the hypothesized limiting factor of carrying capacity. Because of this we picked only the single best covariate (Brown Trout <460 mm) to include in subsequent models.

Table 4. Factors limiting the proportion of Brown Trout >460mm related to carrying capacity of the Beaverhead River.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Carrying capacity	Total trout biomass	Asymptotic	None	0.343	--
Carrying capacity	Brown Trout Biomass	Asymptotic	Negative	0.022	11.4%
Carrying capacity	Brown Trout Biomass t to t-3	Asymptotic	Negative	0.036	10.2%
Carrying capacity	Relative weight	Asymptotic	Positive	0.020	11.8%
Carrying capacity	Relative weight t to t-3	Asymptotic	Positive	0.011	14.9%
Carrying capacity	Brown Trout <460 mm	Negative	Negative	0.000	59.0%

Density of trophy Brown Trout is limited by discharge, carrying capacity, and occurrence of sediment events. The model that included the best covariate from evaluation of each potential limiting factor most parsimoniously predicted the proportion of Brown Trout >460 mm. The lowest Mallows Cp (4.0) and S (0.0601) and highest R^2 (78.6%) resulted from the model that included all three covariates. The resulting model was:

proportion of brown trout > 460mm = 0.264 + 0.000567 mean overwinter discharge – 0.000095 brown trout <460 mm – 0.0667 sediment event.

The trophy Brown Trout model provides strong inference for development of future management alternatives. On average, model predictions deviated about 4% from observed proportion of trophy Brown Trout in the population (Figure 8). The good overall fit of this model indicates that limiting factors affecting the proportion of trophy Brown Trout were accurately identified and characterized. Moreover, it increases the likelihood that the future proportion of trophy Brown Trout can be effectively influenced by actively managing limiting factors. Accordingly, we are confident that we can regularly achieve the trophy Brown Trout management goal by using the trophy Brown Trout model to optimize limiting factors.

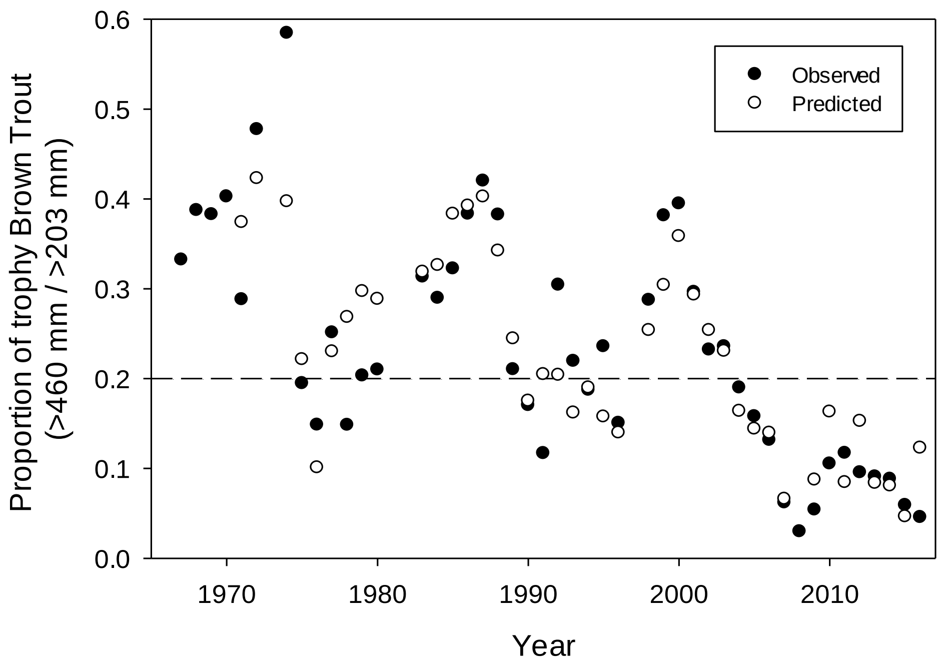

Figure 8. Observed and predicted proportion of trophy Brown Trout in the Beaverhead River. Predictions were made using the most parsimonious model developed by considering the influence of discharge, sediment events, and carrying capacity as limiting factors.

Achieving the management goal for trophy Brown Trout in all years will require management of discharge, sediment events, and density of Brown Trout <460mm because each limit the proportion of trophy fish. We developed management targets based on the covariates and model identified above. To determine minimum overwinter discharge targets, we set the proportion of Brown Trout >460 mm and abundance of Brown Trout >203 mm to our respective management goals of 0.20 and 1600 fish/mile and solved for mean lifetime overwinter discharge in the absence of a sediment event, which was about 105 cfs (Table 5). Accordingly, we recommend a minimum overwinter release of 105 cfs to achieve both of our Brown Trout goals (i.e., 1600 fish per mile with 20% being >460mm). However, if abundance of Brown Trout

<460mm is above 1300 fish per mile at this discharge then it would have to be reduced to achieve our long-term management goal. Similarly, if drought conditions preclude attaining overwinter discharges of 105 cfs then Brown Trout abundance would need to be commensurately reduced to maintain a trophy fishery (Table 5). Occurrence of a sediment event would reduce the proportion of trophy fish by 0.067 (i.e., from 0.20 to 0.13) at any discharge and abundance combination listed in Table 5. By comparison, the same magnitude of reduction would occur if five-year average overwinter discharge was reduced from 105 cfs to 25 cfs and Brown Trout <460 mm was held constant. It is expected that a sediment event can be mitigated through delivery of a flushing flow of a cumulative 2100 acre-feet of water, which is the equivalent of reducing overwinter releases and storing 5 cfs per day for six months (Boyd 2014). Reducing overwinter discharge from 105 cfs to 100 cfs when abundance of Brown Trout >203 mm is 1600 fish per mile results in a 2% decline in proportion of trophy Brown Trout compared to a 38% decline if a sediment event occurs. As such, it is also recommended that managing the discharge regime to provide a flushing flow of at least 600 cfs when Clark Canyon Creek discharges are over 82 cfs be made the highest priority on an annual basis because of the disproportionately large effect of a sediment event. In conclusion, overwinter discharges that average ≥105 cfs over five years and Beaverhead River discharges of 600 cfs whenever Clark Canyon Creek discharges are >82 cfs will allow both Brown Trout population goals to be simultaneously achieved if overall Brown Trout densities are actively managed when necessary.

Table 5. Combinations of discharge and Brown Trout density required to maintain a trophy brown trout fishery in the Beaverhead River in the absence of a sediment event.

Proportion of Brown Trout >460 mm	Mean overwinter discharge from year t to t-4 (cfs)	Sediment event	Brown Trout <460 mm (fish/mi)	Brown Trout >203 mm (fish/mi)	Brown Trout >460mm (fish/mi)
0.2	25	0	823	1029	206
0.2	50	0	972	1215	243
0.2	75	0	1121	1402	280
0.2	100	0	1271	1588	318
0.2	105	0	1300	1625	325
0.2	125	0	1420	1775	355
0.2	150	0	1569	1961	392
0.2	175	0	1718	2148	430
0.2	200	0	1867	2334	467
0.2	250	0	2166	2707	541
0.2	300	0	2464	3080	616

Abundance of Brown Trout >203 mm per mile

Discharge did not appear to limit overall Brown Trout density. Abundance of Brown Trout >203mm was either negatively correlated or uncorrelated with minimum overwinter discharge. We expected that overall abundance of Brown Trout would be positively correlated with overwinter discharge; however, it was negatively correlated with two of the overwinter discharge covariates (minimum for year t, and average from t to t-2) and not correlated with the overwinter discharge metric used in the trophy Brown Trout model (average from t to t-4; Table 6). Moreover, there was no correlation between Brown Trout density and irrigation season discharge. While this relationship is surprising it can probably be best biologically explained by low overwinter discharges reducing the proportion of trophy Brown Trout, which creates space for proportionally more smaller Brown Trout. However, there was no relationship between the number of Brown Trout >460mm and Brown Trout >203mm to corroborate this theory (Table 8). Average discharge in the three previous winters was the only covariate retained in the stepwise model.

Table 6. Factors related to discharge regime that limit the density of Brown Trout >203mm in the Beaverhead River.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Discharge (winter)	Minimum discharge from November 1st to March 31st	Positive	Negative	0.039	9.3%
Discharge (winter)	Mean discharge from November 1st to March 31st	Positive	None	0.069	7.3%
Discharge (winter)	Mean discharge from November 1st to March 31st from year t to t-2	Positive	Negative	0.045	9.5%
Discharge (winter)	Mean discharge from November 1st to March 31st from year t to t-4	Positive	None	0.078	7.5%
Discharge (irrigation)	Mean discharge from April 1st to October 31st in year t-1	Positive	None	0.486	1.1%
Discharge (irrigation)	Mean discharge from April 1st to October 31st from year t-1 to t-4	Positive	None	0.165	4.8%
Discharge (habitat)	Days with discharge >600 cfs in year t-1	Positive	None	0.377	1.8%
Discharge (habitat)	Mean days per year with discharge >600 cfs from year t-1 to t-4	Positive	None	0.155	5.0%

There was no relationship between overall Brown Trout abundance and sediment events that occur either immediately before sampling or in the previous year (Table 7). This is especially surprising given the apparent relationship between low abundance and occurrence of sediment events; abundance goals for Brown Trout (i.e., > 1600 fish per mile) have been met for 28 of the past 30 years and the two exceptions (2006, 2010) were years when sediment events from Clark Canyon Creek were known to have occurred immediately prior to sampling. Abundances were about half of average in two of the three years when sediment events occurred prior to sampling and were slightly below average in the third. Nonetheless, occurrence of sediment events was excluded from the population goal model.

Table 7. Factors related to occurrence of a sediment event originating from Clark Canyon Creek that limit density of Brown Trout >203mm in the Beaverhead River.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <300 cfs) in year t-1	Negative	None	0.786	0.2%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <600 cfs) in year t-1	Negative	None	0.192	3.8%
Sediment Event	Sediment event (CC Q >80 cfs &BVHD Q <600 cfs) in year t-1	Negative	None	0.542	0.9%
Sediment Event	Sediment event (CC Q / BVHD Q >25%) in year t-1	Negative	None	0.176	4.1%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <300 cfs) in year t	Negative	None	0.383	1.7%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <600 cfs) in year t	Negative	None	0.383	1.7%
Sediment Event	Sediment event (CC Q >80 cfs &BVHD Q <600 cfs) in year t	Negative	None	0.915	0.0%
Sediment Event	Sediment event (CC Q / BVHD Q >25%) in year t	Negative	None	0.478	1.1%

It was unclear whether carrying capacity limits the population. Relative weight was asymptotically related to Brown Trout density as expected. As relative weight increases the density of Brown Trout decreases to a point and then remains stable. Low relative weights at high densities suggest that carrying capacity may limit the population and the asymptote may be used as a potential management threshold. The asymptote is reached at about 1400 fish per mile, which corresponds to an upper relative weight of about 95. However, there was no relationship between the proportion of Brown Trout >460 mm and the total population size. Lack of a relationship given the unexpected negative correlation between overwinter discharge, which is positively correlated with the proportion of Brown Trout >460 mm, and Brown Trout >203 mm indicates that different factors drive the trophy and overall populations. Additionally, Brown Trout density is positively, rather than negatively, correlated with Rainbow Trout density which suggests that carrying capacity may not limit the population.

Table 7. Factors related to carrying capacity that limit density of Brown Trout >203mm in the Beaverhead River.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Carrying capacity	Wr	Asymptotic	Asymptotic	0.014	18.1%
Carrying capacity	Brown Trout >460 mm	Negative	None	0.407	4.1%
Carrying capacity	Rainbow Trout >203 mm	Negative	Positive	0.003	17.3%

Carrying capacity appeared to primarily limit the population, although our best model explained little of the variation in density of Brown Trout <203mm. When combining covariates from the respective limiting factors the lowest Mallows Cp (1.3) and S (655.8) and highest R^2 (18.1%) resulted from the model that included only relative weight. The model was:

density of brown trout > 230mm = 48116 – 959 Wr + 4.91 Wr^2.

However, the model that considered only trend outperformed all hypothesized limiting factors in predicting density of Brown Trout >203mm (Table 8). This model predicts increasing density of Brown Trout >203 mm regardless of other limiting factors through time and suggests carrying capacity for Brown Trout in the Beaverhead River is increasing, which may mask the influence of other limiting factors and explain the poor fit of limiting factor-based models. To evaluate whether this occurs we reevaluated covariates for each limiting factor in stepwise regression models that included trend. The proportion of Brown Trout >460 mm and sediment events where discharges were >30 cfs in Clark Canyon Creek coinciding with discharges <600 cfs in the Beaverhead River prior to sampling in year t were included with trend in the respective stepwise models for their limiting factors. However, the relationship between Brown Trout >460 mm and >203 mm was positive, indicating that the density of trophy fish does not explain variation in the data related to carrying capacity. As such, we only included sediment event in our overall trend model (R^2 = 46.2%), which was as follows:

density of brown trout > 230mm = -67525 + 34.7 year – 811 sediment event.

Table 8. Trend of Brown Trout >203mm in the Beaverhead River through time. All models include trend as a covariate and *P* values for models other than trend correspond to the covariate within the model rather than the overall model (all model *P* values are 0.000).

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
None	Trend	None	Positive	0.000	37.2%
Carrying capacity	Brown Trout >460 mm	Negative	Positive	0.035	43.5%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <600 cfs) in year t	Negative	Negative	0.010	46.2%

The overall Brown Trout density model provides adequate inference to develop future management alternatives in the context of the population goal. On average, model predictions were within about 380 fish of, or deviated an average of 30% from, observed Brown Trout densities and were not statistically different than the observed density in about 58% of years (Figure 8). This model made predictions solely based on a constant increase through time with downward adjustments when sediment events occur. The largest deviations from observed values occurred in consecutive years (1975, 1976) with very high abundances relative to previous and subsequent years and a year (1990) where a sediment event was predicted but no population response was observed. If these three outliers are eliminated, then model fit is improved; predictions were reduced to being within 295 fish of or deviated an average of 25% from predicted values. Ultimately, the overall predictive ability of this model should be put in the context of the Brown Trout density goals. All predicted future densities will exceed the Brown Trout density goal (1600 fish per mile; Figure 9). Moreover, the average deviations between observed densities and model predictions were smaller than the deviations between future predictions and the model goal (i.e., at least 900 fish/mile and 56%). Therefore, we are reasonably confident that overall Brown Trout densities will typically exceed our population goal in future years in the absence of management.

Overall density of Brown Trout appears to be driven by increasing carrying capacity and occurrence of sediment events. Brown Trout abundance increases through time irrespective of discharge, which was unexpected. The density of Brown Trout >203 mm is predicted to be 2200 fish per mile in 2017 and to increase by about 350 fish per mile every decade. Density was lower in years when sediment events occur; a sediment event will reduce Brown Trout density by about 811 fish. The model predicts the abundance goal for Brown Trout (≥ 1600 fish >203mm per mile) will be exceeded in future years in the absence of a sediment event until 2018, at which point it will be exceeded regardless of a sediment event (Table 9). It is not possible for Brown Trout densities to limitlessly increase as the model suggests and an upper carrying capacity will be reached eventually. Increases in density must be accompanied by increases in overwinter discharge to achieve our goal for trophy Brown Trout; however, discharges are negatively correlated (*P*=0.003, R^2=18.3%) with time and are expected to decline in the future(Table 9). Thus, active management of Brown Trout densities will likely be required to achieve both population goals. This confirms our finding that the abundance goal for Brown Trout will be met in all years where we manage for a trophy fishery and overwinter discharges are greater than 105 cfs, although it is likely attributable to different factors (i.e., increased carrying capacity) than we initially expected.

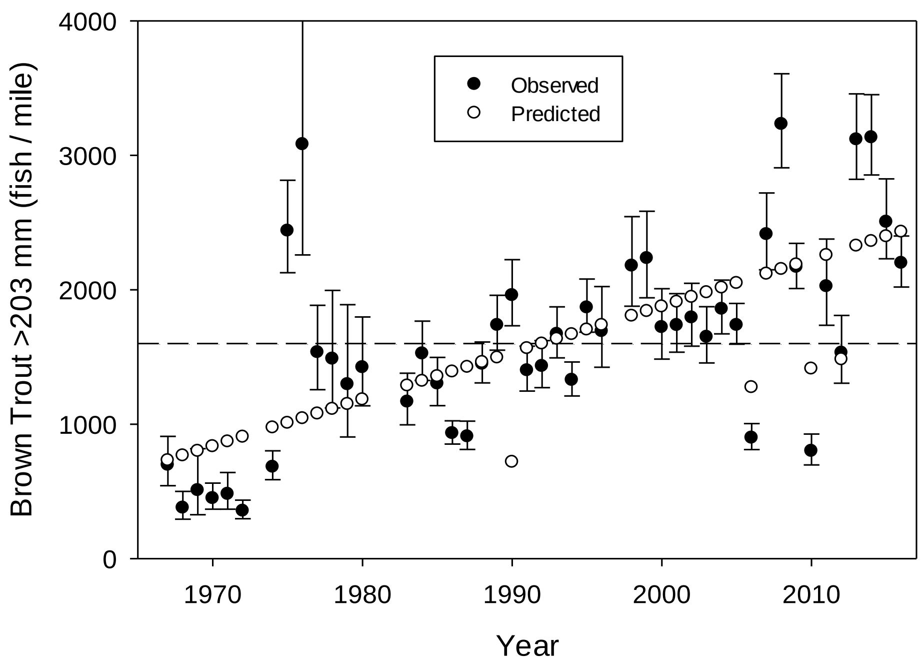

Figure 9. Observed and predicted density of Brown Trout >203 mm in the Beaverhead River. Predictions were made using the most parsimonious model developed by considering the influence of discharge, sediment events, and carrying capacity as limiting factors. The population goal (1600 fish/mile) is described by the dashed line.

Table 9. Predicted densities of Brown Trout without and with sediment events, minimum average overwinter discharges required to meet the Brown Trout trophy goal given predicted densities, and predicted overwinter discharges for the Beaverhead River through time.

Year	Brown Trout >203 mm	Brown Trout > 203 mm with sediment event	Minimum trophy overwinter discharge	Predicted overwinter discharge
1970	834	0	25	264
1980	1181	370	25	220
1990	1528	717	75	177
2000	1875	1064	125	133
2010	2222	1411	175	89
2020	2569	1758	200	46
2030	2916	2105	250	25

Proportion of Rainbow Trout>460 mm

The proportion of trophy Rainbow Trout was influenced by similar discharge covariates as trophy Brown Trout, although they explained less variation in the data. There were positive correlations between proportion of trophy Rainbow Trout and average lifetime overwinter, year t overwinter, and average lifetime irrigation season discharges (Table 10). However, these models individually explained less variation in proportion of trophy Rainbow Trout than the corresponding models for Brown Trout. For example, average lifetime overwinter and irrigation season discharges described 18.4% and 9.6% of the variation in proportion of trophy Rainbow Trout but 51.2% and 46.7% of the variation in trophy Brown Trout. Moreover, there were fewer statistically significant correlations between discharge covariates and trophy Rainbow Trout than for trophy Brown Trout. Redd scouring, which was the only new factor evaluated, appears to either not occur or not significantly affect the proportion of trophy Rainbow Trout. However, all three individually significant covariates were included in the stepwise model (R^2 = 31.8%) indicating that they explain different aspects of variation in proportion of trophy Rainbow Trout whereas all discharge covariates described similar variation in trophy Brown Trout. Thus, discharge is influential to the proportion of trophy Rainbow Trout but in different ways and less so overall than for trophy Brown Trout.

Table 10. Factors limiting the proportion of Rainbow Trout >460mm related to discharge regime in the Beaverhead River.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Discharge (winter)	Mean discharge from November 1st to March 31st	Positive	Positive	0.021	11.8%
Discharge (winter)	Mean discharge from November 1st to March 31st from year t to t-5	Positive	Positive	0.005	18.4%
Discharge (irrigation)	Mean discharge from April 1st to October 31st in year t-1	Positive	None	0.298	2.6%
Discharge (irrigation)	Mean discharge from April 1st to October 31st from year t-1 to t-4	Positive	Positive	0.049	9.6%
Discharge (habitat)	Days with discharge >600 cfs in year t-5	Positive	None	0.100	6.9%
Discharge (habitat)	Days with discharge >600 cfs in year t-1	Positive	None	0.320	2.4%
Discharge (habitat)	Mean days per year with discharge >600 cfs from year t-1 to t-4	Positive	None	0.056	9.1%
Discharge (habitat)	Change in mean discharge May to March t-4	Negative	None	0.724	0.3%
Discharge (habitat)	Change in mean discharge May to March t-5	Negative	None	0.079	7.5%

There was no correlation between the proportion of trophy Rainbow Trout and sediment events originating from Clark Canyon Creek. As with Brown Trout abundance, the proportion of trophy Rainbow Trout were at their lowest values coincident with sediment events; however, no sediment event covariates produced statistically significant models with or without inclusion of year as an additional covariate to account for trend (Table 11). Although raw examination of data suggests that sediment events had a negative effect on trophy Rainbow Trout they may be less influential than for Brown Trout. Regardless, it was not included in subsequent models.

Table 11. Factors limiting the proportion of Rainbow Trout >460mm related to occurrence of a sediment event originating from Clark Canyon Creek.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q >300 cfs) in year t-1	Negative	None	0.332	2.2%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q >600 cfs) in year t-1	Negative	None	0.748	0.2%
Sediment Event	Sediment event (CC Q >80 cfs &BVHD Q >600 cfs) in year t-1	Negative	None	0.225	3.4%
Sediment Event	Sediment event (CC Q / BVHD Q >25%) in year t-1	Negative	None	0.135	5.1%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <300 cfs) in year t	Negative	None	0.290	2.6%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <600 cfs) in year t	Negative	None	0.290	2.6%
Sediment Event	Sediment event (CC Q >80 cfs &BVHD Q <600 cfs) in year t	Negative	None	0.875	0.1%
Sediment Event	Sediment event (CC Q / BVHD Q >25 %) in year t	Negative	None	0.135	5.1%

The proportion of trophy Rainbow Trout was significantly correlated with the Brown Trout population. There were no correlations between the proportion of trophy Rainbow Trout and total trout biomass or covariates specific to the Rainbow Trout population, with the exception of a positive correlation with lifetime condition (Table 12). However, there were significant negative correlations with density of Brown Trout >203mm, <460mm and a positive correlation with Brown Trout >460mm (Table 12). The stepwise model included only Brown Trout <460 mm and >460 mm. These correlations suggest the proportion of trophy Rainbow Trout may be limited by overall trout carrying capacity in the Beaverhead River.

The most parsimonious goal-based model included all covariates included in the respective limiting factor stepwise models (Mallows Cp = 6, S = 0.10638, R^2 47.9%). This model suggests that the proportion of trophy Rainbow Trout is limited by carrying capacity and discharge. High trophy Rainbow Trout densities can be achieved by a combination of relatively low mean irrigation season discharges and densities of Brown Trout <460mm and relatively high mean overwinter discharges and densities of Brown Trout >460mm. The model was as follows:

proportion of Rainbow Trout >460 mm = 0.545 - 0.000078 density Brown Trout <460 mm + 0.000222 density Brown Trout > 460mm + 0.000207 mean overwinter discharge year t + 0.00127 mean overwinter discharge year t to t-5- 0.000841 mean irrigation season discharge year t-1 to t-4.

Table 12. Factors limiting the proportion of Rainbow Trout >460mm related to carrying capacity of the Beaverhead River.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Carrying capacity	Total trout biomass	Asymptotic	None	0.434	1.4%
Carrying capacity	RB Biomass	Asymptotic	None	0.761	0.2%
Carrying capacity	RB Biomass t to t-3	Asymptotic	None	0.542	0.9%
Carrying capacity	RB Relative weight	Asymptotic	None	0.067	7.6%
Carrying capacity	RB Relative weight t to t-3	Asymptotic	Positive	0.013	14.4%
Carrying capacity	Brown Trout >203mm	Negative	Negative	0.002	19.5%
Carrying capacity	Brown Trout >460mm	Positive	Positive	0.033	10.2%
Carrying capacity	Brown Trout <460mm	Negative	Negative	0.000	27.3%
Carrying capacity	Brown Trout Biomass	Negative	None	0.089	6.6%

The trophy Rainbow Trout model provides only moderate inference for development of future management alternatives for trophy Rainbow Trout, but strongly supports our management recommendations for Brown Trout. On average, model predictions deviated about 7% from observed proportion of trophy Rainbow Trout in the population (Figure 10). The decreased predictive precision of this model relative to the trophy Brown Trout model is expected given its lower R^2 (47.9% versus 78.6%); this model explains less of the observed variation in the proportion of trophy Rainbow Trout than the corresponding Brown Trout model. The practical interpretation based on the above deviation between observed and predicted values is that about half the time the predicted proportion of trophy Rainbow Trout will be within 0.07 of the actual value. As with the Brown Trout density model, the predictive power of this model should be placed in the context of its management goal. Because of the positive correlation between the proportion of trophy Brown and Rainbow Trout and greater complexity of the trophy Rainbow Trout model, we recommended simply managing for thresholds identified by the trophy Brown Trout model to meet both trophy trout goals. It should be recognized there is more uncertainty in the outcome of management actions intended to influence factors that limit the proportion of trophy Rainbow Trout than with Brown Trout, but that our uncertainty is primarily related to the magnitude trophy Rainbow Trout will benefit from management. Accordingly, there is negligible risk associated with attempting to manage the identified limiting factors because we are confident they will benefit trophy Brown Trout and not harm trophy Rainbow Trout. Given the concordance of limiting factors and associated management actions between trophy Rainbow and Brown Trout the trophy Rainbow Trout model is adequate to inform our management direction; it suggests our recommendations (i.e., actively manage to attain the trophy Brown Trout goal) will improve the proportion of trophy Rainbow Trout, but it is unclear to what degree.

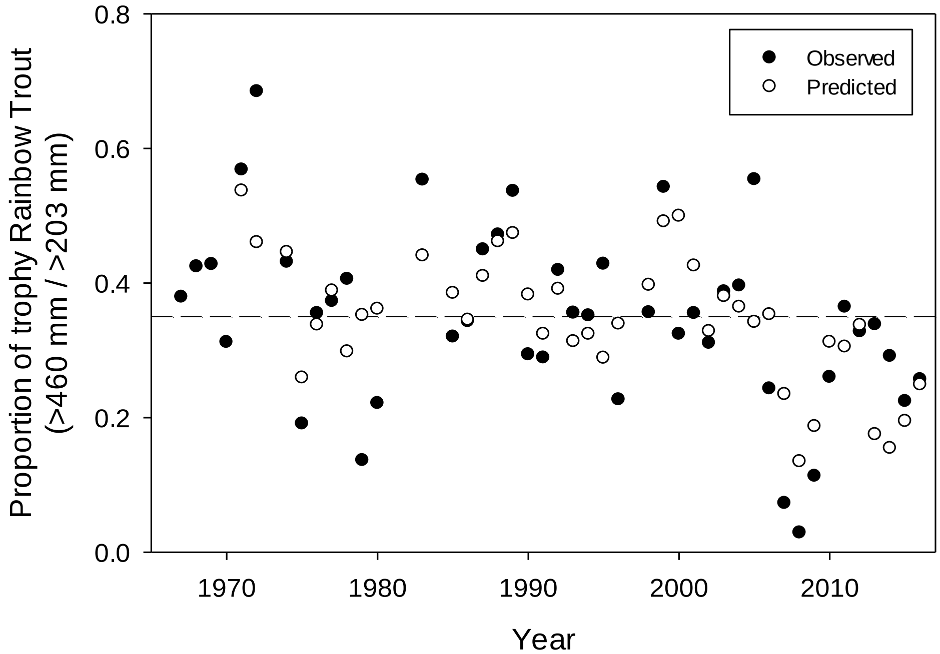

Figure 10. Observed and predicted proportion of trophy Rainbow Trout in the Beaverhead River. Predictions were made using the most parsimonious model developed by considering the influence of discharge, sediment events, and carrying capacity as limiting factors.

It is evident that similar factors affect the proportion of trophy Rainbow and Brown Trout; therefore, we also modeled trophy Rainbow Trout as a function of trophy Brown Trout as follows:

proportion of Rainbow Trout >460 mm = 0.205 + 0.616 proportion of Brown Trout >460 mm

We will use the trophy Brown Trout model to set management thresholds for trophy Rainbow Trout. This model did not perform as well as the limiting factor-based goal model for trophy Rainbow Trout; however, it was statistically significant (P = 0.000) and described 36.6% of the variation in the data. This model also has a considerable advantage in simplicity over the limiting factor-based model. Developing species-specific sets of management thresholds for discharge and abundance is cumbersome to implement and difficult to convey to and gain acceptance for from stakeholders. This model predicts that when the goal for trophy Brown Trout is met (i.e., is 0.2) that the proportion of rainbow trout in the population would be 0.33. To compare this estimate to those generated by the previous model over a range of abundances and discharges we used the discharge specific Brown Trout abundances required to meet the Brown Trout Trophy goal from Table 5 and estimated mean irrigation season discharge as a function of mean overwinter discharge (P=0.000, R^2=86.8%). The two models provided essentially identical estimates of the proportion of trophy Rainbow Trout (Table 13). Given the differences in how discharge affects the proportion of trophy Rainbow and Brown trout it is likely that the goal-based model will provide better predictions of the proportion of trophy Rainbow Trout when discharges vary among years (they were held constant for this exercise), although the trophy Brown Trout model is likely adequate for setting thresholds. Therefore, the management thresholds for trophy Rainbow Trout are recommended to be the same as for trophy Brown Trout (Table 5).

Table 13. Proportion of trophy Rainbow Trout predicted by models using proportion of trophy Brown Trout (trophy Brown Trout model) and identified limiting factors (Rainbow Trout goal model) as covariates.

Proportion of Brown Trout >460 mm	Mean overwinter discharge t to t-4 (cfs)	Mean irrigation season discharge t to t-4 (cfs)	Brown Trout <460 mm per mile	Brown Trout >460 mm per mile	Proportion of Rainbow Trout >460 mm (trophy Brown Trout model)	Proportion of Rainbow Trout >460 mm (Rainbow Trout goal model)
0.2	25	275	823	206	0.33	0.33
0.2	50	312	972	243	0.33	0.34
0.2	75	348	1121	280	0.33	0.34
0.2	100	385	1271	318	0.33	0.34
0.2	105	392	1300	325	0.33	0.34
0.2	125	422	1420	355	0.33	0.34
0.2	150	459	1569	392	0.33	0.35
0.2	175	495	1718	430	0.33	0.35
0.2	200	532	1867	467	0.33	0.35
0.2	250	606	2166	541	0.33	0.36
0.2	300	679	2464	616	0.33	0.36

Abundance of Rainbow Trout >203 mm per mile

There were positive correlations between Rainbow Trout density and discharge, although irrigation season discharge metrics were better predictors than overwinter discharge (Table 14). We expected that overwinter discharge would be most likely to limit trout populations because it reduces the amount of available habitat more than irrigation season discharge in any given year (FWP 1989). Rainbow Trout density may be better correlated with irrigation season discharge because it is influenced more by habitat quality than quantity; higher quality habitat may be created at higher peak flows because of mobilization and flushing of fine sediment from substrate. This theory is corroborated by the stepwise model, which included only mean number of days >600 cfs (the discharge where effective sediment flushing occurs) over the previous four years.

Table 14. Factors limiting the proportion of Rainbow Trout >203 mm related to overwinter discharge, occurrence of sediment events originating from Clark Canyon Creek, and carrying capacity of the Beaverhead River.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Discharge (winter)	Mean discharge from November 1st to March 31st	Positive	None	0.250	3.7%
Discharge (winter)	Mean discharge from November 1st to March 31st from year t to t-2	Positive	None	0.075	7.7%
Discharge (winter)	Mean discharge from November 1st to March 31st from year t to t-5	Positive	Positive	0.001	26.1%
Discharge (irrigation)	Mean discharge from April 1st to October 31st year t-1	Positive	Positive	0.008	15.7%
Discharge (irrigation)	Mean discharge from April 1st to October 31st from year t-1 to t-4	Positive	Positive	0.000	37.7%
Discharge (habitat)	Days with discharge >600 cfs in year t-1	Positive	Positive	0.006	16.6%
Discharge (habitat)	Mean days per year with discharge >600 cfs from year t-1 to t-4	Positive	Positive	0.000	36.5%

Rainbow Trout density was not correlated with sediment events (Table 15). This is surprising based on raw examination of data (the two lowest Rainbow Trout densities in the past 30 years occurred in years with sediment events) but consistent with the effect of this potential limiting factor on Brown Trout density and proportion of trophy Rainbow Trout.

Table 15. Factors limiting the proportion of Rainbow Trout >203 mm related to occurrence of a sediment event originating from Clark Canyon Creek.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q >300 cfs) in year t-1	Negative	None	0.229	3.4%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q >600 cfs) in year t-1	Negative	None	0.229	3.4%
Sediment Event	Sediment event (CC Q >80 cfs &BVHD Q >600 cfs) in year t-1	Negative	None	0.769	0.2%
Sediment Event	Sediment event (CC Q / BVHD Q >25%) in year t-1	Negative	None	0.378	1.8%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <300 cfs) in year t	Negative	None	0.219	3.5%
Sediment Event	Sediment event (CC Q >30 cfs &BVHD Q <600 cfs) in year t	Negative	None	0.219	3.5%
Sediment Event	Sediment event (CC Q >80 cfs &BVHD Q <600 cfs) in year t	Negative	None	0.611	0.6%
Sediment Event	Sediment event (CC Q / BVHD Q >25%) in year t	Negative	None	0.583	0.7%

Density of Rainbow Trout >203 mm do not appear to be limited by a fixed carrying capacity. All examined covariates had the opposite relationship we would expect if Rainbow Trout density was influenced by carrying capacity, except for density of Brown Trout >460mm which was not correlated with Rainbow Trout >203mm (Table 16). Accordingly, the examined carrying capacity covariates were not considered further.

Table 16. Factors limiting the proportion of Rainbow Trout >203 mm related to overwinter discharge, occurrence of sediment events originating from Clark Canyon Creek, and carrying capacity of the Beaverhead River.

Potential limiting factor	Covariate	Hypothesized relationship	Observed relationship	*P*	R^2
Carrying capacity	Rainbow Trout relative weight	Asymptotic	Positive	0.037	9.7%
Carrying Capacity	Rainbow Trout > 460mm	Negative	Positive	0.000	72.1%
Carrying Capacity	Brown Trout biomass	Negative	Positive	0.000	32.1%
Carrying Capacity	Brown Trout >203 mm	Negative	Positive	0.005	17.3%
Carrying Capacity	Brown Trout <460 mm	Negative	Positive	0.027	10.9%
Carrying Capacity	Brown Trout >460 mm	Negative	Positive	0.005	17.2%
Carrying Capacity	Proportion Brown Trout >460mm	Negative	None	0.796	0.2%

Our overall model to predict density of Rainbow Trout >203mm included only the average number of days >600 cfs over the previous four years. This, it appeared Rainbow Trout density was limited by high irrigation season discharges. As with density of Brown Trout >203mm, we explored whether there was a trend through time whose inclusion may improve the fit of other covariates but there was none (P = 0.261, R^2 = 2.9%). Therefore, our final model for overall Rainbow Trout density (P = 0.000, R^2 = 36.5%) was:

Rainbow trout >203 mm = 150 + 7.65 Mean days per year with discharge >600 cfs from year t-1 to t-4.

The overall Rainbow Trout density model provides limited inference to develop future management recommendations. On average, model predictions were within about 238 fish of, or deviated an average of 42% from, observed Rainbow Trout densities and were not statistically different than the observed density in about 63% of years (Figure 11). However, the predictive ability of this model improves through time; in 17 of the past 20 years (85%) predicted Rainbow Trout densities were not significantly different than observed densities. This was partly due to the relatively poor precision of Rainbow Trout abundance estimates in general and in the late 1990s and early 2000s in particular. Nonetheless, this model accurately depicts the observed fluctuations in Rainbow Trout density through time, even though it only describes about 36.5% of the overall variation in the data. The low R^2 for this model may be a function of the relatively low precision of the response variable (i.e., estimated Rainbow Trout density) muting the true influence of a significant limiting factor (i.e., days >600 cfs). Alternatively, there may be other population drivers that we did not evaluate that explain the remaining variation in the population. Regardless, there is the greatest amount of uncertainty in the outcome of model-based management thresholds and recommendations for Rainbow Trout density among the four goals. As with Brown Trout density, the population goals is usually met so the risk of negatively affecting Rainbow Trout density by implementing model-based recommendations within a given irrigation season (i.e., maximizing the number of days with discharges >600 cfs) may be low. However, making tradeoffs that reduce the likelihood of achieving other trout population goals (i.e., reducing overwinter releases to deliver more days >600 cfs during the irrigation season) is not warranted given the collective uncertainty in this model. Therefore, the management thresholds developed using this model should be implemented such that they do not negatively affect the ability to meet the trophy Brown and Rainbow Trout goals.

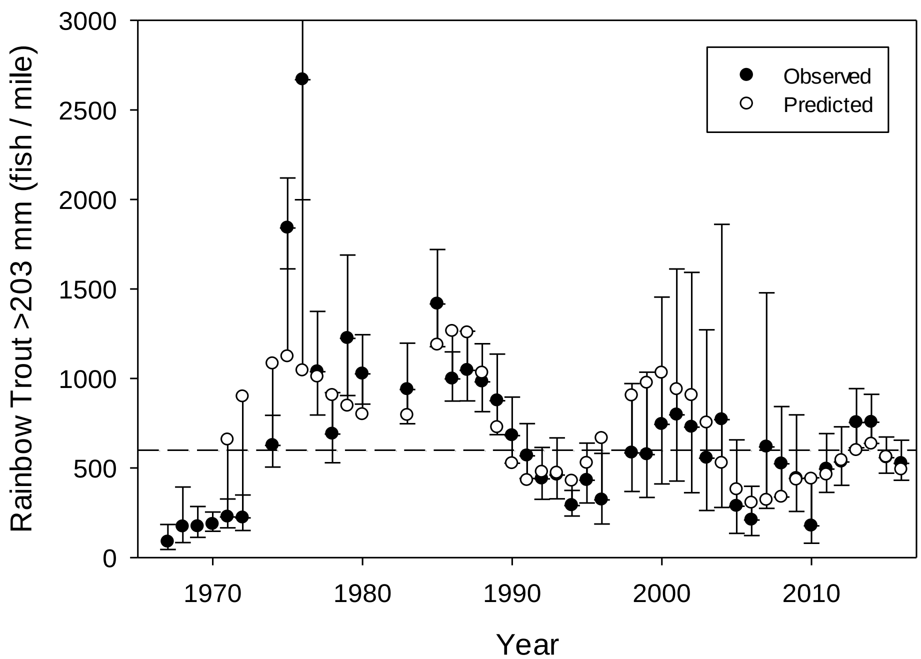

Figure 11. Observed and predicted density of Rainbow Trout >203 mm in the Beaverhead River. The management goal for density of Rainbow Trout >203mm can be met by delivering discharges ≥600 cfs for 59 days a year (Table 16). We expect that this goal will be met in most years; on average there are about 73 days per year where discharges are ≥600 cfs. However, four-year averages during periods of extended drought in the 1980s, 2000s, and 2010s were 36, 20, and 44, respectively. Thus, it is likely that our goals for Rainbow Trout density will not be met during periods of extended drought.

Table 16. Predicted density of Rainbow Trout >203 mm per mile as a function of mean days >600 cfs in the Beaverhead River.

Average number of days >600 cfs	Rainbow Trout > 203 mm per mile
10	227
20	303
30	380
40	456
50	533
60	609
70	686
80	762
90	839
100	915

Discussion

Density and proportion of trophy Brown and Rainbow Trout were affected differently by the evaluated limiting factors. We hypothesized that each population goal was influenced by a combination of discharge regime, sediment events, and carrying capacity. The influence of these limiting factors was assessed based on evaluation and, ultimately, inclusion of covariates related to each limiting factor in a model that provides the most efficient annual predictions relative to our actual observations over the past 50 years. Our approach indicated that only trophy Brown Trout were limited by each factor; covariates for discharge regime, sediment events, and carrying capacity were included in its final population model. However, it is possible that trophy Rainbow Trout were also limited by each factor. The best trophy Rainbow Trout model included covariates related to discharge regime and carrying capacity but not sediment events. Similar discharge and Brown Trout population covariates were included in each trophy fish model, but the Rainbow Trout model additionally included a positive effect related to density of trophy Brown Trout. This could be explained in two ways: 1) both trophy populations are driven by a common factor we did not evaluate or 2) trophy Rainbow Trout are affected by sediment events but we did not accurately characterize them, so the model is describing their influence via their effect on trophy Brown Trout. Sediment events were also not included in the Rainbow Trout density model, but coarse examination of both datasets reveals that historically low values coincide with known sediment events. We resultantly favor the latter interpretation that sediment events limit both trout populations and their influence on Rainbow Trout was not detected because they were not accurately characterized. Poor characterization of sediment events likely results from the quality of available discharge information for Clark Canyon Creek; only annual peak flows are recorded so other factors that may define a sediment event (i.e., intra-annual duration or frequency of high flows) could not be analyzed. Overall density of both trout species did not appear to be limited by a fixed systemic carrying capacity. Rather, it appears that carrying capacity fluctuates among years based on other limiting factors; Rainbow Trout density was most influenced by frequency of high flows (i.e., >600 cfs) while Brown Trout density was influenced by an undescribed factor that is increasing through time, with the most likely alternative being systemic productivity. The proportion of trophy Rainbow Trout was similarly influenced by high discharge, which suggests that Rainbow Trout are more sensitive to overall habitat quality than Brown Trout. Although overall density and proportion of trophy Brown and Rainbow Trout are limited by different factors, this analysis indicates their populations are influenced by conditions occurring over multiple years; the best models for population goals other than Brown Trout density included discharge covariates that spanned at least four years. As such, management alternatives should be developed and implemented such that conditions likely to result in attainment of population goals are achieved in as many consecutive years as possible.

Achieving management goals in the Beaverhead River will involve a combination of managing overwinter releases, sediment events, and Brown Trout densities. Although models for each population goal include different covariates there are commonalties among them. For example, sediment events may negatively affect Brown and Rainbow Trout. Brown Trout densities negatively affect the proportion of trophy Rainbow and Brown Trout. Moreover, the proportion of trophy Rainbow Trout is positively correlated with the proportion of trophy Brown Trout, so managing for conditions that favor one trophy population will benefit the other. Because Brown Trout density is predicted to increase regardless of other factors, management alternatives can be simplified to focus on conditions that will achieve the remaining trout population goals. Accordingly, based on our assessment of population drivers, we expect that all trout management goals can be simultaneously achieved if 1) overwinter releases are ≥105 cfs, 2) Beaverhead River discharge is ≥600 cfs when Clark Canyon Creek discharge is >80 cfs, and 3) there are ≥60 days where discharge is ≥600 cfs each year. However, if Brown Trout densities are not actively managed the value of optimizing discharge regimes is lost. Brown Trout densities must be actively managed based on average overwinter discharges as described in Table 5 to regularly achieve population goals.

Achievement of all goals can occur under most conditions if Brown Trout densities and sediment events are actively managed. An average discharge regime produces an overwinter discharge of 175 cfs and 74 days above ≥600 cfs. In the absence of a sediment event these conditions are expected to produce about 2500 Brown Trout >203mm per mile and 725 Rainbow Trout >203 mm per mile. If the density of Brown Trout >203mm is reduced to 2100 fish per mile by reducing the density of fish <460mm to 1700 fish per mile then at least 20% of Brown Trout and 33% to 41% of Rainbow Trout will be trophy fish. By comparison, if Brown

Trout abundances are not managed under average conditions there would be about 400 more <460mm but 30 fewer >460 mm Brown Trout per mile than if the population was managed. If a sediment event occurred there would be about 335 fewer <460 mm and 140 fewer >460 mm Brown Trout per mile than if management occurred. Management is not expected to affect the density of Rainbow Trout, but there would be about 80 fewer fish >460 mm per mile without management. As described above, all goals can be simultaneously met down to discharges of 105 cfs and ≥60 days where discharge is ≥600 cfs if management alternatives that limit Brown Trout densities and address sediment events are implemented. Thus, development of effective management strategies to reduce Brown Trout densities and the effect of sediment events is required to regularly achieve population goals.

Management goals for both overall abundance and proportion of trophy fish cannot be simultaneously met during drought years. As described above, density of Brown Trout <460 mm must be reduced as overwinter discharge declines to maintain at least 20% of Brown Trout and 35% of Rainbow Trout >460mm (Table 13). However, as density of fish <460 mm is reduced overall Brown Trout abundance declines, eventually resulting in population densities of less than 1600 individuals per mile (Table 5). At average overwinter discharges below 105 cfs a tradeoff exists where density of Brown Trout <460 mm must be reduced to the levels described in Table 5 or trophy Brown and Rainbow Trout will decline to the point they are functionally eliminated from the fishery. Irrigation releases also decline during drought conditions resulting in a reduction of days ≥600 cfs each year, although there is no clear management action to mitigate for this other than requesting that this value be maximized to the extent possible. The most extreme drought scenario can be described by overwinter discharges of 25 cfs (minimum releases required by Reclamation) and 20 days ≥600 cfs each year (the minimum four-year average value on record). If Brown Trout densities are managed according to Table 5 to provide trophy fisheries, then we predict that there will be about 1000 Brown Trout per mile with 200 being >460 mm and 300 Rainbow Trout per mile with about 100 being >460 mm. If Brown Trout density is not managed but sediment events are, the resulting population is expected to be comprised of about 2500 Brown Trout per mile with about 100 being >460 mm and 300 Rainbow Trout per mile with none being >460 mm. Thus, overall Brown Trout abundances would be reduced by about 50%, but density of trophy fish of both species would be at least doubled if management occurs. If a sediment event occurs under the above extreme drought scenario then we expect a population comprised of 1600 Brown Trout and 300 Rainbow Trout per mile with no fish of either species being >460 mm. At overwinter discharges between 105 and 25 cfs intermediate values occur.

Replicating historically high levels of abundance and proportion of trophy fish is more dependent on consecutive good water years than management. Consecutive years of above average discharge may result in population goals being exceeded regardless of management.

During the three periods with the highest proportions of trophy fish (i.e., 1974, 1987, 2000) discharges during the five previous winters averaged over 300 cfs and there were over 115 days with ≥600 cfs. Under these conditions we predict there would be about 2500 Brown Trout >203 mm per mile, 25% of which would be >460 mm, and 1000 Rainbow Trout >203 mm per mile with up to 40% being >460 mm. If a sediment event occurred when discharges were <600 cfs then overall Brown Trout densities would be reduced to about 1650 fish per mile, but all other values would be similar. Thus, during good conditions either no management or management of sediment events will result in the population substantially exceeding our goals. However, historically high abundances and proportions of trophy fish cannot be achieved in the absence of favorable conditions regardless of management.

Management Recommendations

The following management recommendations are primarily relevant to time periods with consecutive years of average or below average conditions. As described, no population management is required during periods with consecutive years of high discharge, although it will always be beneficial to ensure there is at least 600 cfs in the Beaverhead River concurrent with a sediment event. As such, we recommend the following actions to achieve the management goals described in this report:

1) Manage discharges to ensure there is at least 105 cfs in as many consecutive years as possible. We expect this may require reducing overwinter discharges relative to present BOR targets in some years and banking the difference to use if drought conditions occur in subsequent years.
2) Reduce Brown Trout densities when they are above the discharge-specific criteria presented in table 5. This could be done by increasing harvest limits to 25-50 Brown Trout <406 mm (16 in) daily and in possession with no Rainbow Trout, which would focus harvest on almost exclusively 2- to 3-year-old Brown Trout. This regulation should apply to the reach of the Beaverhead River between High Bridge and Grasshopper FAS, where brown trout <406 mm dominate the population. Upstream of High Bridge FAS should be catch and release for trout with artificial lures only to minimize the effect of catch and release mortality on trophy fish, which comprise over 90% of the population in that reach.
3) Deliver at least 600 cfs in the Beaverhead River anytime Clark Canyon Creek discharges are >80cfs. This would be achieved by reducing overwinter discharges by 5 cfs and storing the cumulative 2100 acre-feet of water for a sediment flushing flow as described by Boyd (2014).
4) Make a general recommendation to irrigators that the number of consecutive days with discharges >600 cfs be maximized to the extent possible.

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