Effects of a modified flow regime on the fish populations of the Crooked River below Bowman Dam

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Abstract

The Crooked River in central Oregon supports an extremely popular Redband Trout (*Oncorhynchus mykiss*) fishery that is also inhabited by resident Mountain Whitefish (*Prosopium williamsoni*), anadromous steelhead trout and Chinook Salmon (*O. tshawytscha*). Annual monitoring documented a significant decline in the Redband Trout population from 1,383 trout/kilometer in 2015 to 185 trout/kilometer in 2016. Operation of Bowman Dam has altered the discharge regime to be opposite of that historically encountered. In addition, the outlet structure of Bowman Dam causes nitrogen to become supersaturated in the river at high discharge. Consequently, low winter discharge and high spring discharge have significant negative effects on all fish populations. The recently passed Crooked River Jobs and Security Act allows the use of uncontracted storage in Prineville Reservoir to be released downstream for the benefit of fish populations. Thus far, this water has been released during the summer in response to elevated water temperature in the Crooked River downstream of the city of Prineville. Oregon Department of Fish and Wildlife encourages sufficient water be released during the winter to provide enough quality overwintering habitat for resident trout and juvenile steelhead and Chinook Salmon in the highest priority reaches; from Bowman Dam to Ochoco Irrigation District's (OID) diversion and from OID's diversion to the city of Prineville.

Introduction

The Crooked River below Bowman Dam has become one of central Oregon's premier trout fishing destinations. This is due to abundant populations of native Redband Trout (*Oncorhynchus mykiss* ssp.), a subspecies of Rainbow Trout, and Mountain Whitefish (*Prosopium williamsoni*) in addition to year round fishing opportunity when other local streams are closed during winter. This 13 kilometer section of river (river kilometer [rkm] 99-112) is managed by the U.S. Bureau of Land Management (BLM) as a Wild and Scenic River and the fishery was identified as an Outstanding Remarkable Value. This classic tailwater fishery has the potential to support productive fish populations through hypolimnetic release of consistently cool water from Bowman Dam. Favorable rearing and foraging conditions for native fish species are provided, even during the hot, dry summers typically encountered in Central Oregon. In addition to resident trout and whitefish, steelhead (anadromous Rainbow Trout) and Chinook Salmon (*O. tshawytscha*) have been reintroduced into the Crooked River with spawning adults returning near the base of Bowman Dam. The Oregon Department of Fish and Wildlife (ODFW) monitors the resident fish populations annually to track longterm health through density estimates, size distribution and body condition. These data are used to effectively implement fish management practices and evaluate the impacts of water management on fish populations.

The suspected most significant limiting factor affecting fish populations in the Crooked River is quantity and timing of flows released from Bowman Dam. Bowman Dam was completed in 1961 with authorized purposes to provide flood control and water for irrigation. The impounded Crooked River water creates Prineville Reservoir. Releases from the dam have resulted in the natural flow regime being reversed from high flows in late winter and low flows in summer and early fall to high flows in the summer (irrigation releases) and low flows in the winter (to refill the upstream reservoir).

During high discharge from Bowman Dam, nitrogen becomes entrained in water to levels that are deleterious to fish through a condition known as gas bubble disease. Gas bubble disease involves the formation of bubbles within the tissues of an organism that results in visible external signs or internal bubbles that result in tissue damage or mortality when the bubbles form emboli and block the flow of blood (Weitkamp and Katz 1980). Nesbit (2010) estimated total dissolved gas (TDG) levels reach the Oregon Department of Environmental Quality (ODEQ) maximum level of 110% at a discharge of 600 cubic feet per second (cfs) and 120% saturation at 1,200 cfs below Bowman Dam. Dawley et al. (1976) estimated significant mortality of juvenile Chinook Salmon and steelhead commenced at about 115% saturation when hydrostatic compensation was not possible through the lack of deep water. A one meter increase in depth results in a 10% reduction in saturation.

Insufficient flow in the winter causes a multitude of effects but the most serious is a reduction in the quality and quantity of available habitat for all aquatic organisms. In 2016, fish populations were subjected to both low flow during winter and high flow during spring.

There is clear consensus that modified flow regimes affect fish and fish habitat, but the severity and direction of the response varies greatly (Murchie et al. 2008). The objective of this paper is to analyze and discuss the impacts of the modified flow regime on the aquatic community in the Crooked River, specifically the Redband Trout population, and make recommendations to protect and enhance fish populations.

Methods

Sampling

ODFW conducted population estimates for Redband Trout in 1989, 1993-1995, 2001, 2003 and annually from 2006-2016. Annual monitoring was initiated in 2006 in response to angler concerns regarding low trout densities and to determine the impacts of dam modifications on the trout population. Population estimates for Mountain Whitefish were also conducted annually from 2007-2016. The surveys estimated the number of Redband Trout and Mountain Whitefish per kilometer (fish/km) that were ≥ 200 mm long with the exception of 1989 when estimates were based on the number of trout/km that were ≥ 180 mm long. The 200 mm length was selected to be consistent with the current harvestable size limit. The surveys were conducted in the same 4.2 km reach from Big Bend Campground (rkm 111.9) to Cobble Rock Campground (rkm 107.7) each year with the exceptions of 1989 and 2001 (Figure 1). Samples were collected for eight km in 1989 whereas samples were collected for only 2.1 km of the standard reach in 2001. The standard reach was selected based on accessibility for a sampling boat and because the influences of flow management on fish populations are most pronounced near the dam. Fish were collected the third week of June each year using a boat-mounted electrofisher manned by a rower and two netters. Trout were collected the entire length of the sampling reach but whitefish were collected only for the first 0.8 km. All fish collected were identified to species, measured for total length to the nearest mm, and a subsample was weighed to the nearest gram. All trout and whitefish that were ≥ 200 mm long were marked with a hole punch in the tail. Smaller size class trout and whitefish were also captured, but were not included in the population estimate. Samples were collected for five consecutive days; marks were applied for the first four days of sampling and fish were checked for marks the last four days. Population estimates for trout and whitefish were calculated using a Schnabel multiple-census estimator along with 95%

confidence intervals (Van Den Avyle and Hayward 1999). Density of both species was calculated by dividing the population estimate by the length of the sampling reach, 4.2 km for trout and 0.8 km for whitefish.

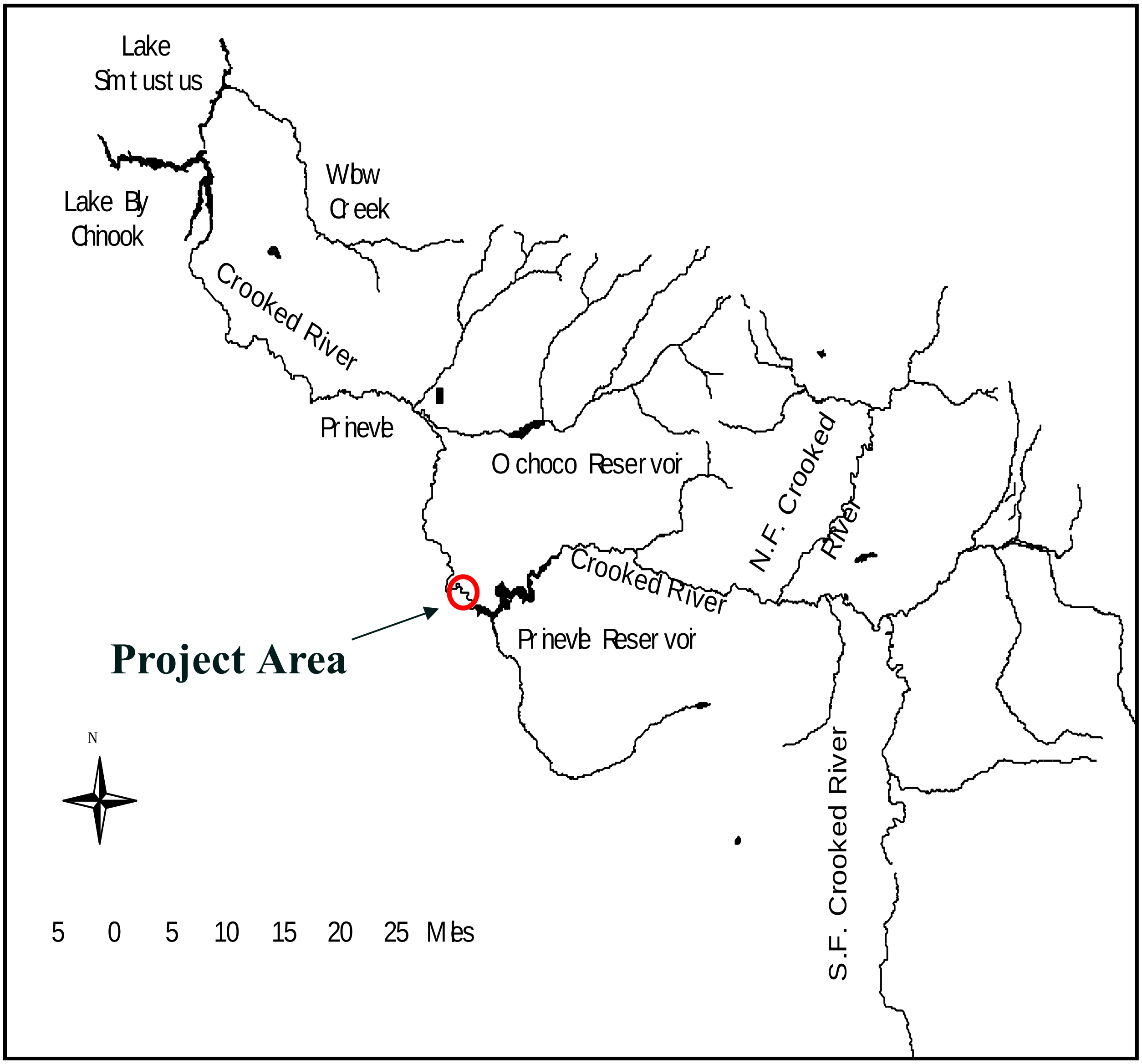


Figure 1. Map of the Crooked River Watershed with the project area highlighted by a red circle.

Data analysis

Redband Trout density estimates from 2006-2016 were plotted against the daily mean discharge using data from January 1, 2005 to June 30, 2016 collected at the U.S. Bureau of Reclamation (BOR) gauge near the base of Bowman Dam (PRVO) to determine if relationships existed that warranted further analyis. For the analysis, we divided the water year into three seasons, winter, spring and summer. We defined winter as October through February. This time period corresponded to the non-irrigation/storage season and when reservoir management was following the flood control rule curve. Spring was defined as March through June, corresponding to the filling of the reservoir and when outflow was more likely to be high and unstable depending on precipitation and snowmelt. Summer was defined as July through September; the irrigation season when discharge was generally more stable. Winter discharge was highly variable but November had the lowest mean discharge so was selected to represent winter discharge in the model. Data from the winter prior to the density estimate were used in the analyses to evaluate the effects of winter discharge on the trout population. Throughout this report, discharge is described as low and high. There is not a value to quantify low and high but was defined as discharge within a water year relative to mean annual discharge for the specified season.

The relationship between mean November discharge, mean spring discharge and estimated trout density was modeled using linear regression and plotted against the observed data. Common model diagnostics were used to evaluate the appropriateness of using linear models to evaluate trout density. Five models were fit that included additive effects and interactions of mean November and spring discharge, as well as an intercept only model. Each model represented an *a priori* hypothesis about the data-generating process. Akaike's information criterion corrected for small sample size (AIC_c), AIC_c weights, and ΔAIC_c values were used to evaluate model parsimony and compare models (Burnham and Anderson 2002). The AIC_c weight represents the relative likelihood of each model being the correct model given the models and the data. The change in AIC_c value (i.e., ΔAIC_c) relative to the top model (i.e., the model with the lowest AIC_c value) was used to compare models where a ΔAIC_c value of less than two suggests substantial evidence for that model compared to the top model, and values greater than ten suggest that the model is very unlikely when compared to the top model. Model-averaged parameter estimates were also calculated for models with a ΔAIC_c value of less than two. Leave-one-out cross validation was used to evaluate the fit and predictive performance of the top model (Efron and Gong 1983). Relative root mean squared error was used as the metric from the cross validation exercise as the measure of predictive ability.

Results

Sampling

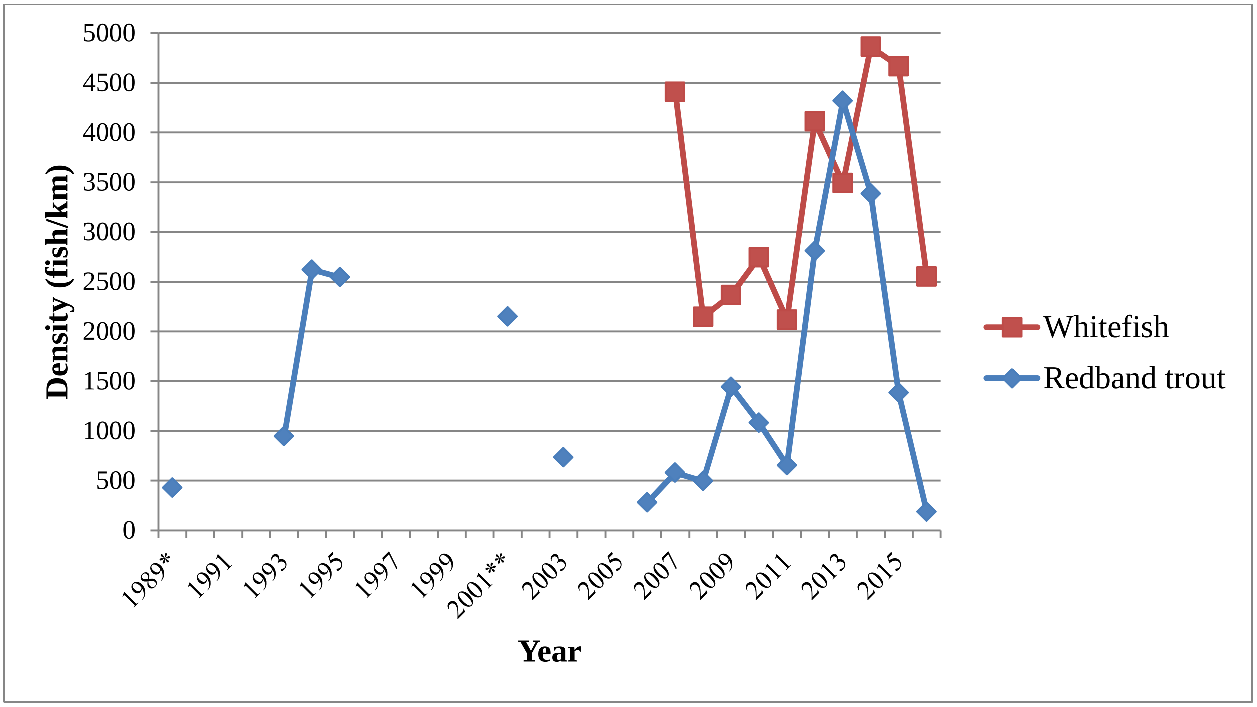
The density estimate of Redband Trout in 2016 was the lowest ever recorded at 185 trout/km, an 87% reduction from the 2015 estimate of 1,383 trout/km (Table 1 and Figure 2). Estimated Mountain Whitefish density declined 45% from 4,667 whitefish/km in 2015 to 2,553 whitefish/km in 2016 (Table 1 and Figure 2). Throughout the monitoring period (1989-2016), when trout density was low, the recapture rate of marked fish was variable resulting in less precise estimates, as demonstrated by relatively wide confidence intervals. The length distribution of Redband Trout in 2016 was dominated by fish between about 60 and 240 mm (Figure 3), which differs from previous years when larger fish were more abundant (Figure 4).

Table 1. Density estimates (number of fish/km with 95% confidence intervals in parentheses) of Redband Trout and Mountain Whitefish ≥ 200 mm long in a 4.2 km reach below Bowman Dam on the Crooked River 1989-2016. Missing data indicates an estimate was not conducted for the corresponding year.

Year	Redband Trout	Mountain Whitefish
1989*	516 (364-786)	
1993	945 (677-1,415)	
1994	2,620 (2,164-3,240)	
1995	2,545 (2,160-3,045)	
2001**	2,150 (1,887-3,126)	
2003	733 (430-1,036)	
2006	281 (176-518)	
2007	578 (329-1,288)	4,409 (3,206-6,463)
2008	494 (324-756)	2,146 (1,493-3,081)
2009	1,443 (1,016-2,216)	2,366 (1,529-3,651)
2010	1,081 (786-1,584)	2,746 (1,815-4,661)
2011	654 (471-972)	2,118 (1,634-2,858)
2012	2,809 (2,109-3,752)	4,111 (2,623-7,404)
2013	4,319 (3,365-5,757)	3,490 (2,609-4,917)
2014	3,386 (2,963-3,909)	4,861 (3,778-6,497)
2015	1,383 (1,200-1,632)	4,667 (3,896-5,819)
2016	185 (124-362)	2,553 (2,063-3,348)

* Estimated fish ≥ 180 mm in an 8 km long reach

** 2.1 km long reach



* Estimated fish ≥ 180 mm in an 8 km long reach
** 2.1 km long reach

Figure 2. Redband Trout and Mountain Whitefish density (fish/km) estimates 1989-2016. Missing data indicates an estimate was not conducted for the corresponding year.

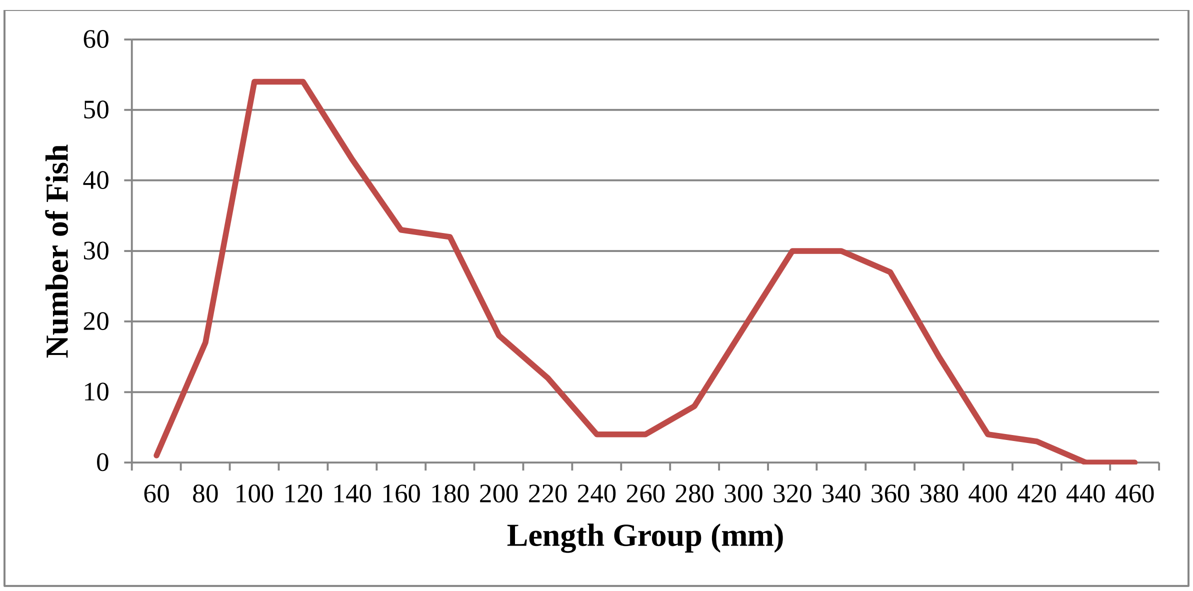


Figure 3. Length frequency of Redband Trout collected from the Crooked River below Bowman Dam 2016.

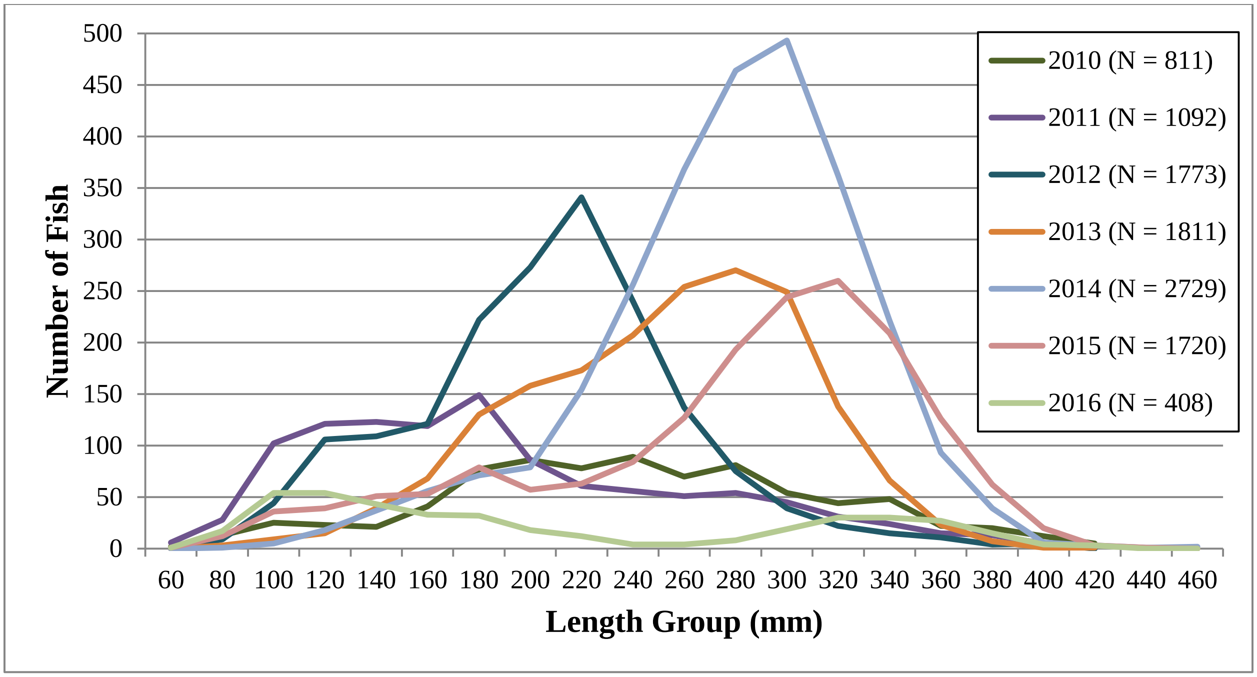


Figure 4. Length frequencies of Redband Trout collected from the Crooked River below Bowman Dam 2010-2016.

Upon completion of the irrigation season in fall of 2015, discharge was reduced to approximately 50 cfs at the beginning of October for a period of 58 days and then further reduced to approximately 35 cfs for 50 days (Figure 5), which coincided with extremely cold weather and below freezing water temperature (Figure 6). Discharge was then regulated based on inflow into Prineville Reservoir, storage capacity of the reservoir and rule curves established for flood control by the BOR. Discharge peaked at nearly 2,000 cfs for three days from March 7 through March 9, 2016. Discharge was greater than 600 cfs for 44 days and greater than 1,200 cfs for eight.

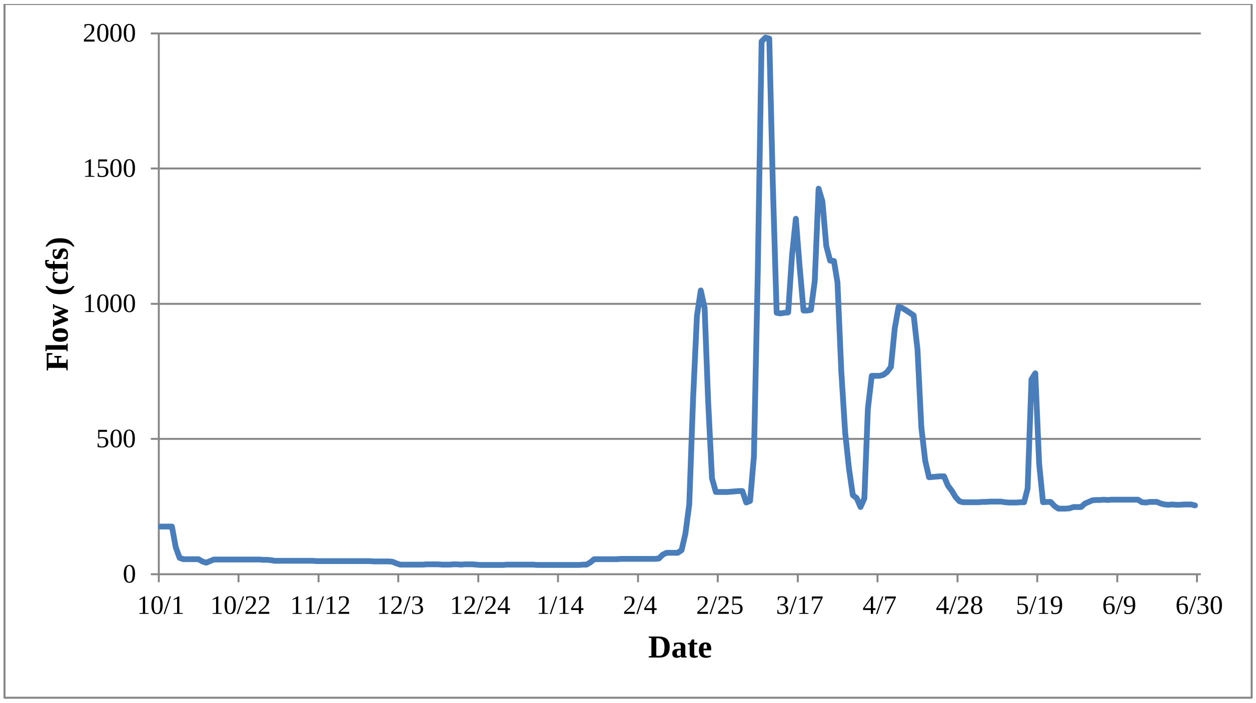


Figure 5. Mean daily discharge (cfs) measured at U.S. Bureau of Reclamation Crooked River near Prineville, OR (PRVO) gauge from October 1, 2015 to June 30, 2016.

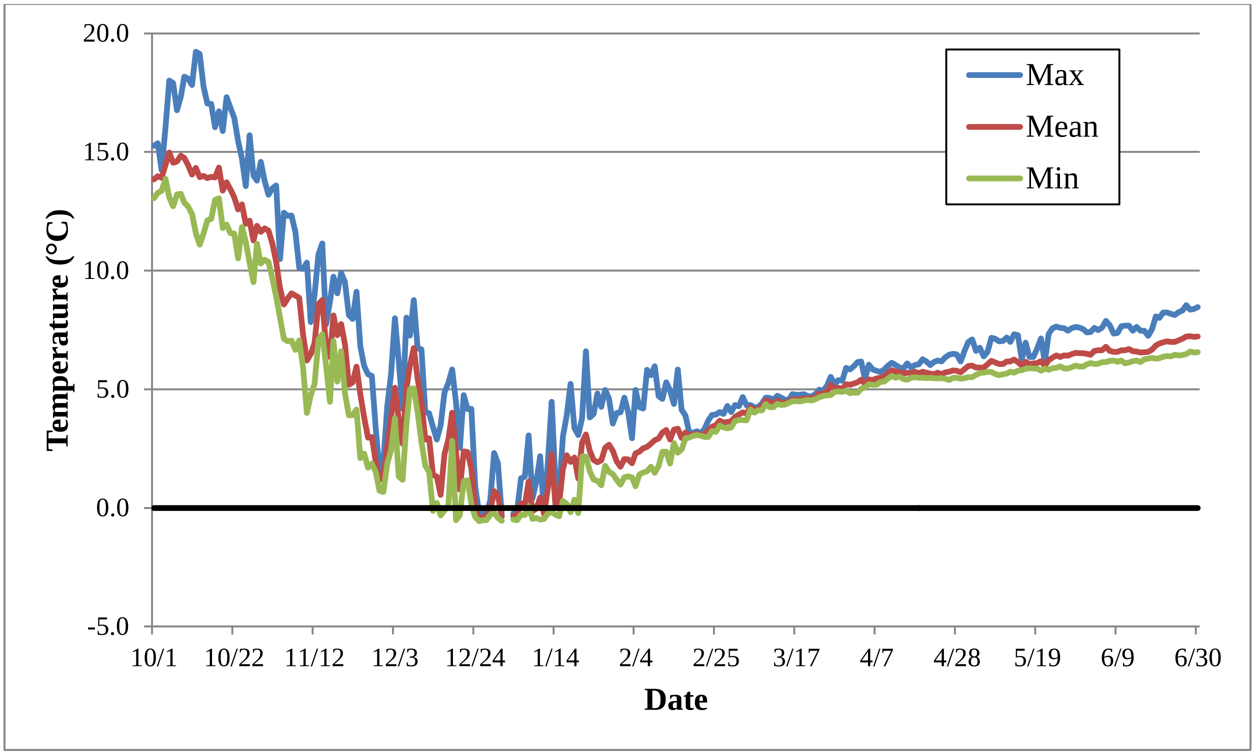


Figure 6. Water temperature (°C) measured at U.S. Bureau of Reclamation Crooked River near Prineville, OR (PRVO) gauge from October 1, 2015 to June 30, 2016. Solid black, horizontal line indicates freezing temperature (0°C).

Data analysis

Redband Trout density appeared to decrease in years that experienced low winter discharge, high spring discharge or both when compared to years of average discharge with trout density data (Figure 7). The top model of the five evaluated included the additive effects of mean November discharge and mean spring discharge (Table 2). This model accounted for nearly half of the AIC_c weight. Although the model that included the additive effects of discharge was the top model, two additional models; the intercept-only model, which did not account for any discharge-related effects, and the spring discharge model both had a ΔAIC_c value of less than two, suggesting that they also have substantial support. The coefficients of the top model were negative for spring discharge and positive for November discharge (Table 3). As mean spring discharge increased, trout density declined (Figure 8). As mean November discharge increased, trout density increased (Figure 9) . The model-averaged coefficients were similar to the top model (Table 4). The predictive capability of the top model, evaluated using the cross-validation exercise, was relatively low with a relative root mean squared error of 51% (i.e., on average predicted density in a given year was 51% more or less than the observed density) (Figure 10). The low predictive ability was likely a result of the relatively small sample size and large variability in Redband Trout density.

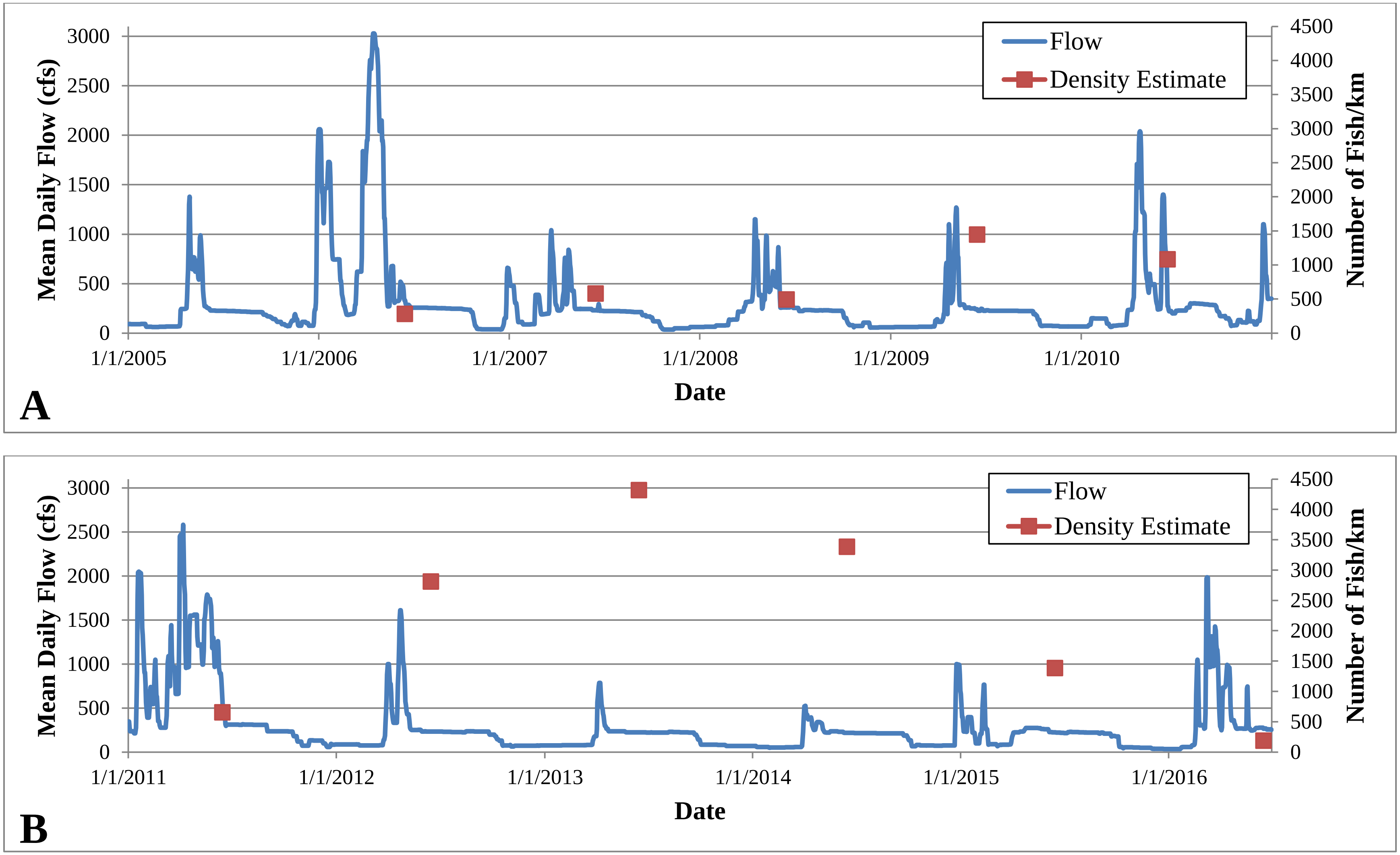


Figure 7. Redband Trout density estimates (number of fish/km) plotted against mean daily discharge (cfs) measured at U.S. Bureau of Reclamation Crooked River near Prineville, OR (PRVO) gauge from January 1, 2005 to June 30, 2016. January 1, 2005 to December 31, 2010 is displayed in panel A and January 1, 2011 to June 30, 2016 is displayed in panel B.

Table 2. Comparison of models used to evaluate the effect of discharge on Redband Trout density in the Crooked River.

Model	K	AIC_c	ΔAIC_c	AIC_c weight
Intercept + November discharge + spring discharge	4	207.2	0	0.48
Intercept only	2	208.55	1.34	0.25
Intercept + spring discharge	3	208.79	1.59	0.22
Intercept + November discharge	3	212.33	5.12	0.04
Intercept + November discharge + spring discharge + (November discharge × spring discharge)	5	214.36	7.16	0.01

Table 3. Estimated coefficients from the top model used to evaluate the effect of discharge on Redband Trout density in the Crooked River.

Parameter	Coefficient estimate	Standard error
Intercept	1365.648	1680.71
Spring discharge	-7.948	2.246
November discharge	69.239	26.4

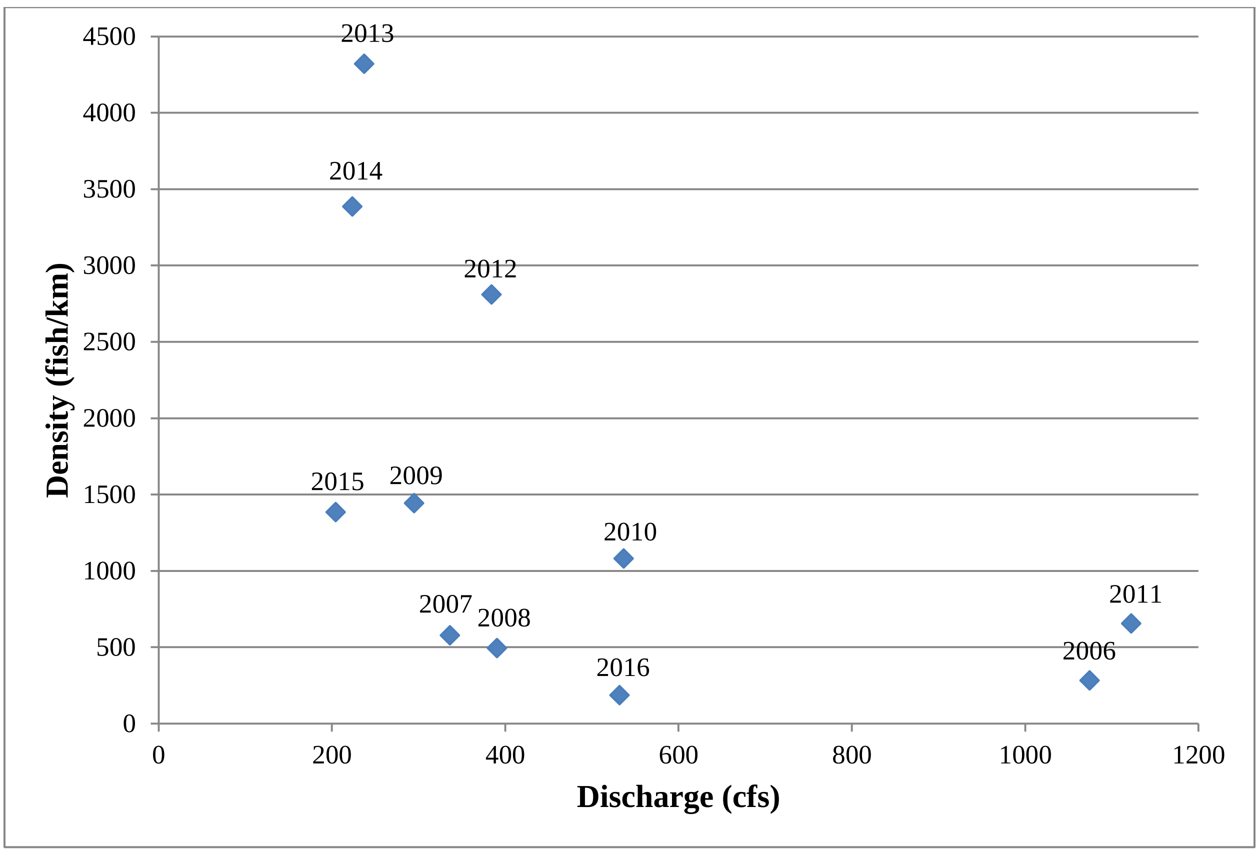


Figure 8. Mean spring discharge plotted versus Redband Trout density 2006-2016.

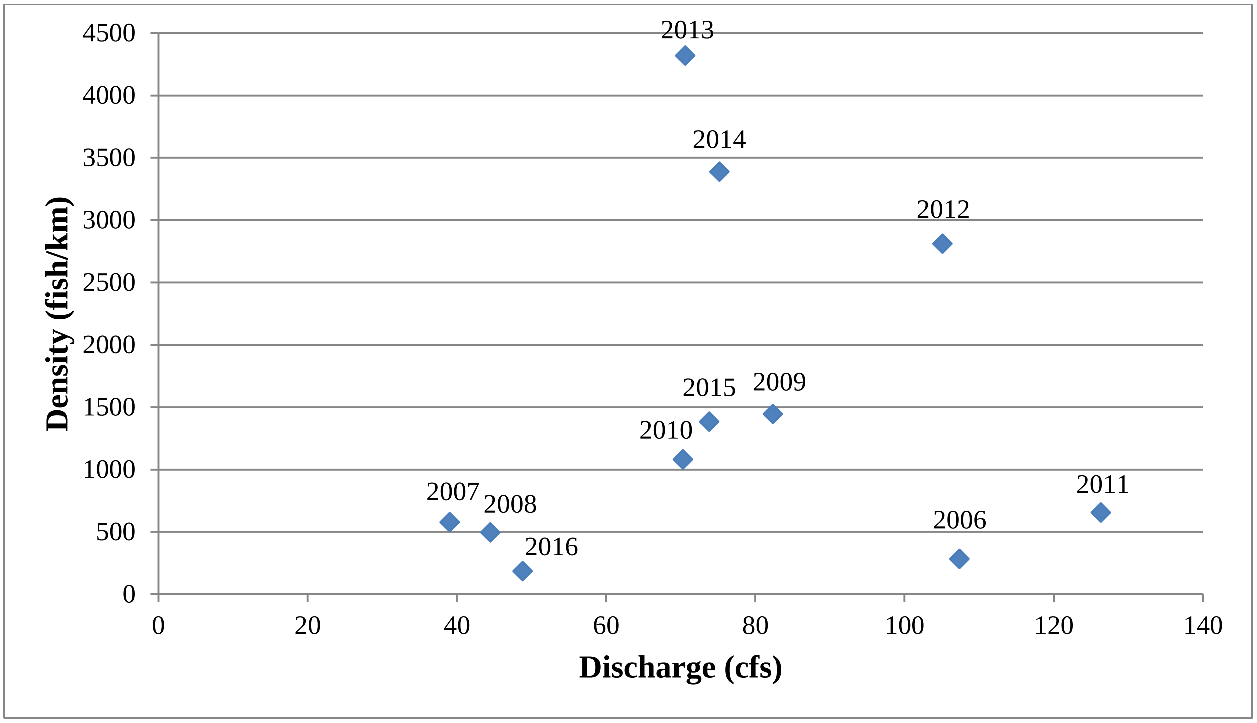


Figure 9. Redband Trout density plotted versus prior mean November discharge (eg. 2016 density estimate vs November 2015 discharge) 2006-2016.

Table 4. Model-averaged estimated coefficients from models used to evaluate the effect of discharge on Redband Trout density in the Crooked River.

Parameter	Coefficient estimate	Standard error
Intercept	2543.8389	2121.0145
Spring discharge	-6.8988	3.3309
November discharge	64.6487	32.2554
November discharge × spring discharge	0.0388	0.1165

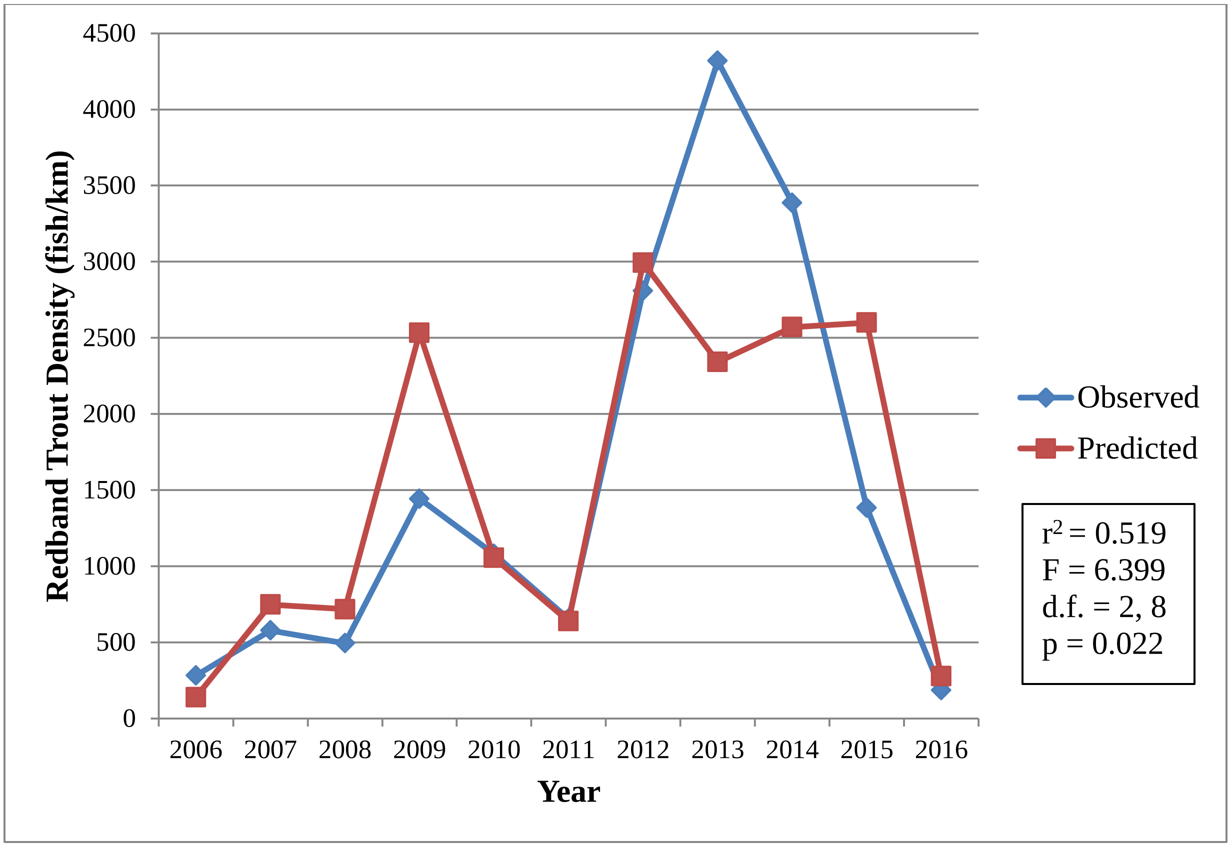


Figure 10. Predicted Redband Trout density estimates (fish/km) from the best performing model using November and spring discharge versus the observed density estimates (fish/km) 2006-2016.

In summary, the density estimate for Redband Trout was the lowest ever recorded at 185 fish/km following winter discharge of 35 cfs for 50 days and spring discharge greater than 600 cfs for 44 days. The low winter discharge also coincided with extremely cold weather that resulted in below freezing water temperature. The size structure of the trout population changed to being dominated by smaller size classes due to the loss of larger fish. Modeling suggested a negative relationship between mean spring discharge and trout density and a positive relationship between mean November discharge and trout density. The top model included the additive effects of mean spring discharge and mean November discharge.

Discussion

Models can be useful tools for fish management, but their reliability depends on monitoring programs that provide data at the appropriate resolution (Korman et al. 2012). When discharge varies, other related variables may be affected, such as water temperature, velocity, depth, width and wetted perimeter (Cushman 1985). There is a need to examine variables that co-vary with flow. We were able to detect a relationship between discharge and Redband Trout density, but including more data on these related variables and increasing the sample size with continued fish population monitoring may increase the explanatory power of the analyses (Murchie et al. 2008).

Our results were consistent with the conclusions of other studies that flow regimes play an important role in fish population dynamics (McKinney et al. 2001, Bunn and Arthington 2002, Dibble et al. 2015). Large declines in the Redband Trout population have occurred in the Crooked River in years that experienced low winter discharge or high spring discharge (Figures 8 and 9). The impacts were worse when both discharge scenarios were encountered in the same year, evidenced by the top model results (Table 2). We propose that these scenarios are the strongest factors affecting fish populations in the Crooked River. We will also discuss other variables that influence fish population dynamics that could partially explain the variability in the Crooked River, either individually or through cumulative effects.

Due to the many variables that are associated with discharge (eg., depth, width, velocity, forage availability, water temperature and quality), it was difficult to determine fish population limiting factors since the strength of impact from each variable may be expressed differently on an annual basis. However, the effects of each variable may be minimized by increasing discharge during the winter. For example, discharge during December 2015 was approximately 35 cfs. During this period, extremely cold weather was experienced which lowered the minimum daily water temperature to at or below freezing for 27 days, causing the river to freeze over and possibly forming anchor ice in the substrate. The lower lethal limit of rainbow trout is 0 degrees Celsius (Bell 1991) suggesting some level of mortality was experienced. Juvenile salmonids have been shown to enter the interstitial spaces of the substrate when the water temperature is approximately 5 degrees Celsius (Bjornn and Reiser 1991). If they did not experience direct mortality from the sub-lethal water temperature, the formation of anchor ice could have induced more mortality by trapping some individuals in the substrate or forced others to seek more suitable habitat which may have led to increased predation or competition or both. Adult salmonids will also seek shelter in the interstitial spaces if the substrate allows or seek cover in deeper pools. The Crooked River has very few deep pools that provide sufficient overwintering habitat, especially at the extremely low discharge encountered in winter 2015-2016.

The combined adult density of Redband Trout and Mountain Whitefish was estimated to be approximately 6,000 individuals/km in June 2015. Winter discharge may have contributed to increased competition for resources, including food and space, between trout and whitefish. Not only would discharge and temperature affect fish, it also likely affected their food source, macroinvertebrates in the substrate and drift through direct mortality and reduced available habitat (Orth 1987).

Our results are consistent with the findings of other studies that determined low winter discharge is detrimental to salmonid populations. In years that experienced extremely low discharge during the winter, trout population estimates were low (Figure 9). We also observed the loss of large individuals and poor recruitment of smaller size classes (Figure 4). These effects were exacerbated in years that also experienced high spring discharge. This is similar to the findings of Fausch et al. (2001) who compared successful, moderate and failed rainbow trout invasions to the hydrologic regimes in their native range. The most successful invasions had hydrologic regimes of winter flooding and summer low discharge that matched those in the native range. The failed invasions had hydrologic regimes of spring or summer flooding and low winter discharge.

Possibly the most serious problem caused by high discharge in the Crooked River that can affect all life stages is gas bubble disease from nitrogen supersaturation. ODFW (1996) estimated approximately 85% of the redband trout collected in 1989 following a high flow event displayed symptoms of gas bubble disease. It was also estimated that 56% of the Redband Trout and 47% of the Mountain Whitefish exhibited signs of gas bubble disease in 2006 following a discharge greater than 1,000 cfs for 17 consecutive days (Nesbit 2010). 1989 and 2006 represented the only two years ODFW staff sampled during active high discharge events monitoring for evidence of gas bubble disease. However, based on the strong correlation between discharge and TDG, Nesbit predicted gas bubble disease may have been present in fish at regular intervals from 1993 – 2016 when discharge exceeded 1,000 cfs. The extent to which TDG and gas bubble disease impacts a fish population is variable, but it has shown to cause direct mortality, injury or indirect mortality through complications of injuries. Duration of high discharge and elevated TDG levels appears to have equal influence on gas bubble disease expression as the magnitude of discharge.

The effects described below are speculative in the Crooked River, but they have been shown to be significant factors in other tailwaters. As such, they are important to discuss as potential influences and deserve investigation.

Rainbow Trout recruitment in tailwaters was primarily explained by dam operations regulating discharge (McKinney et al. 2001, Dibble et al. 2015). Recruitment decreased when spring discharge was high during the period of spawning, egg hatching and fry emergence (Dibble et al. 2015). Recruitment regulates fish population densities and since discharge alters recruitment and prey availability, discharge indirectly impacts the adult size distribution (Dibble et al. 2015).

Discharge influences fish population dynamics and physical variables that co-vary with discharge via many different mechanisms. One such mechanism is timing, duration and magnitude of discharge (Power et al. 1996). The quality and quantity of available spawning habitat may be increased by flushing fine sediment from the interstitial spaces of the substrate as long as this is done outside of the spawning and incubation period or at least does not encompass the entire period (Korman et al. 2011, Avery et al. 2015). Greater discharge may increase the water depth and wetted area which may allow access to off-channel rearing habitat. However, the associated increase in water velocity can also displace juveniles from preferred habitats and alter the abundance and composition of periphyton and invertebrate communities. This would affect the food availability for and survival of juvenile fish. Juvenile trout survival is enhanced by the continuous availability of shallow, slow velocity nearshore areas (McKinney et al. 2001). However, whole year classes may be lost if high discharge persists through the entire spawning and incubation period (Warren et al. 2009).

Dibble et al. (2015) suggested high discharge can be detrimental to adult salmonids by creating a higher energetic demand that can decrease the fish's growth and/or physiological condition when they are constructing redds and attempting to maintain position over them. Spawning requires a high investment of energy; lipid reserves are commonly depleted by more than 50% compared to pre-spawning levels. Lower spring discharge can benefit adult trout by reducing the energetic costs at a time when energy levels are already low.

Similar to high discharge, low discharge can have significant effects on fish populations depending on the timing, duration and magnitude. In a comparison of 29 tailwater fisheries, Dibble et al. (2015) found that the two most important predictors that increased rainbow trout recruitment were high winter/low spring discharge and low annual discharge. When discharge was stable and not excessive during the spring spawning season, redds were not scoured or buried, allowing for better survival of the eggs and fry. Juvenile survival was also enhanced by an increase in low velocity nearshore habitat which allowed for more efficient foraging and protection from predation. High, fluctuating discharge in the spring and summer moved the juvenile fish offshore where there was a higher energetic cost of maintaining position in higher velocity water and increased potential of predation. Optimal discharge maximizes the availability of quality spawning habitat and provides sufficient clean, well oxygenated water without scouring or burying redds and flushing young fish.

Juvenile fish abundance is affected strongly by density-dependent factors. Two of the most critical periods of density-dependent mortality occur 1) shortly after emerging from the gravel where they must compete for limited feeding territories and 2) during the winter when conditions are harshest (Korman et al. 2011). The availability of quality habitat during these periods is critical for survival, which determines recruitment into the adult population.

Ultimately, the alteration of physical characteristics of a river may result in negative consequences for the biodiversity through changes in the availability and suitability of aquatic habitat (Bunn and Arthington 2002, Murchie et al. 2008). Increased winter discharge would mitigate the impacts of water temperature by creating a greater volume of water, thus requiring more energy to effect a change in temperature. Sufficient winter discharge also provides more habitat for fish rearing and macroinvertebrate production. A sufficiently natural discharge regime is critical for river biota and food webs (Power et al. 1996).

In summary, over a 20-year period we observed the greatest decline in Redband Trout densities in the Crooked River from 2015 to 2016. Based on our observations, field data, and literature review, the factors working in concert to which we attribute the decline include:

- Insufficient winter discharge (i.e., lack of available habitat) for a preexisting combined high density of trout and whitefish
- Extremely cold weather causing freezing conditions, possibly exacerbating low discharge effects
- Possible decrease in macroinvertebrate production from insufficient discharge and freezing conditions, resulting in a lack of available forage
- High spring discharge resulted in nitrogen supersaturation and potentially gas bubble disease

Reintroduced anadromous fish populations were not directly sampled or quantified, however, with similar habitat and biological requirements their populations would likely experience the same effects as Redband Trout.

Management implications

Many riverine organisms have a limited range of conditions to which they are adapted and when those conditions are modified, the abundance, diversity and productivity of these organisms are reduced (Cushman 1985). This is mostly due to changes in habitat quality and availability, especially during critical periods (Korman et al. 2011). We propose that there are two critical periods on the Crooked River, 1) during the winter and 2) late spring/early summer when the trout are spawning and young are hatching. The physical attributes of the Crooked River upstream and downstream of the City of Prineville (Prineville) differ and thus have different impacts during these critical periods. The two main bottlenecks impacting the fish populations upstream of Prineville are 1) lack of quality habitat during low winter discharge and 2) gas bubble disease caused by extended high spring discharge. A third bottleneck affecting the salmonid populations downstream of Prineville is high water temperature during the summer. Extreme flow modification during these two critical periods results in significant negative effects to resident salmonid populations as well as sympatric reintroduced anadromous steelhead and Chinook Salmon populations. As such, our data are consistent with that of other studies that determined fish populations are healthiest under natural discharge regimes (Cushman 1985, Power et al. 1996, Poff et al. 1997, Fausch et al. 2001, Freeman et al. 2001, Marchetti and Moyle 2001, Wenger et al. 2011, and Dibble et al. 2015).

While acknowledging discharge cannot be returned to pre-dam conditions, incorporating critically important features of the natural discharge regime to avoid habitat bottlenecks during key salmonid developmental stages may alleviate negative effects (Freeman et al. 2001, Avery et al. 2015). There is the opportunity to do this in the Crooked River as the Crooked River Water and Jobs Security Act allows for the use of uncontracted water from Prineville Reservoir to be used for the benefit of fish and wildlife. Currently, water has been released during the summer in attempt to maintain cooler water temperatures for rearing steelhead and Chinook Salmon in the river downstream of Prineville. The river downstream of Prineville is important to protect, but degraded water quality from water withdrawals and degraded habitat conditions from land use activities render it a lower priority. The Crooked River between Bowman Dam and Prineville is the priority core area as it provides the best available habitat, and with appropriate water management, will provide water quality and quantity conditions favorable for salmonid populations. Hardin (1993 and 2001) calculated the amount of weighted usable area that would be available for Redband Trout and reintroduced anadromous fish species at various flows (Figure 11). He suggested a summer discharge of 140 cfs and winter discharge of 90 cfs are necessary to provide sufficient habitat to support robust and viable salmonid populations in the core area. These charts should be used to determine how to maximize habitat based on the amount of available water. During years of limited water availability, rather than releasing fish and wildlife water during the summer, our data suggest sufficient water should be saved to provide favorable conditions in the core area during critical winter months.

Monitoring should be continued to document fish response to flow modifications and identify optimum conditions. Monitoring should be expanded throughout the year to determine effects associated with seasonal flow patterns. Multiple life-stages should be included to determine the effects on different year classes and factors impacting recruitment to the adult population. Since there are many physical and biological variables related to flow, including water temperature, total dissolved gas and macroinvertebrate production, these factors should be included in the monitoring program which will increase the explanatory power of the analyses. ODFW recommends funds be allocated to implement this extensive monitoring program.

Finally, even though modifications were completed on the outlet structure of Bowman Dam in 2006, gas bubble disease remains a problem in the Crooked River. Necessary modification to the dam should be completed to eliminate or at least minimize the occurrence of gas bubble disease. Making changes to the current discharge regime and outlet structure of the dam will benefit fish populations in the Crooked River. This will improve the likelihood of successful steelhead and Chinook Salmon reintroduction and maintain a healthy and abundant Redband Trout population.

A creel survey conducted by ODFW in 2013 showed that the Wild and Scenic Section below Bowman Dam is an extremely popular fishery (unpublished data). In eight months (May – December), anglers from 30 different states and two international countries expended an estimated 46,543 hours angling. Based on a rough estimate of about 10,300 angler trips, we estimate approximately $600,000 were spent by anglers in trip-related expenditures for this Crooked River fishery in 2013. Trip-related expenditures include costs for transportation (gas, etc.), groceries, restaurants/bars, and overnight accommodations (camping, hotel, B&B) and do not include equipment costs for waders, rods, etc. Much of the angler trip spending occurs in the Prineville. Since the survey data covers only eight months of angling in 2013, the actual number of trips and expenditures would likely be higher for the full year. Angler use is high year round when trout density is good because the Crooked River is one of the few area streams open to fishing during the winter and offers anglers a reasonable chance of a high catch rate. In 2013, anglers were asked to rate their trip satisifaction on a scale of 1 to 5. Anglers were extremely satisfied with their trips, with 88% reporting a score of 4 or 5 (McCormick and Porter 2014). The two main factors influencing this high satisfaction were mean length of fish caught and catch rate. At the time, there was a high number of larger fish compared to 2016 (Figure 4). The season long catch rate in 2013 was estimated to be 1.32 trout per hour (McCormick and Porter 2014). Anectdotal information and angler reports in 2016 suggest angler use, mean length of fish caught and catch rate are only a fraction of what they were compared to 2013. This underscores the importance of this fishery to the local Prineville economy and the necessity of maintaining a healthy Redband Trout population and restored steelhead and Chinook Salmon populations.

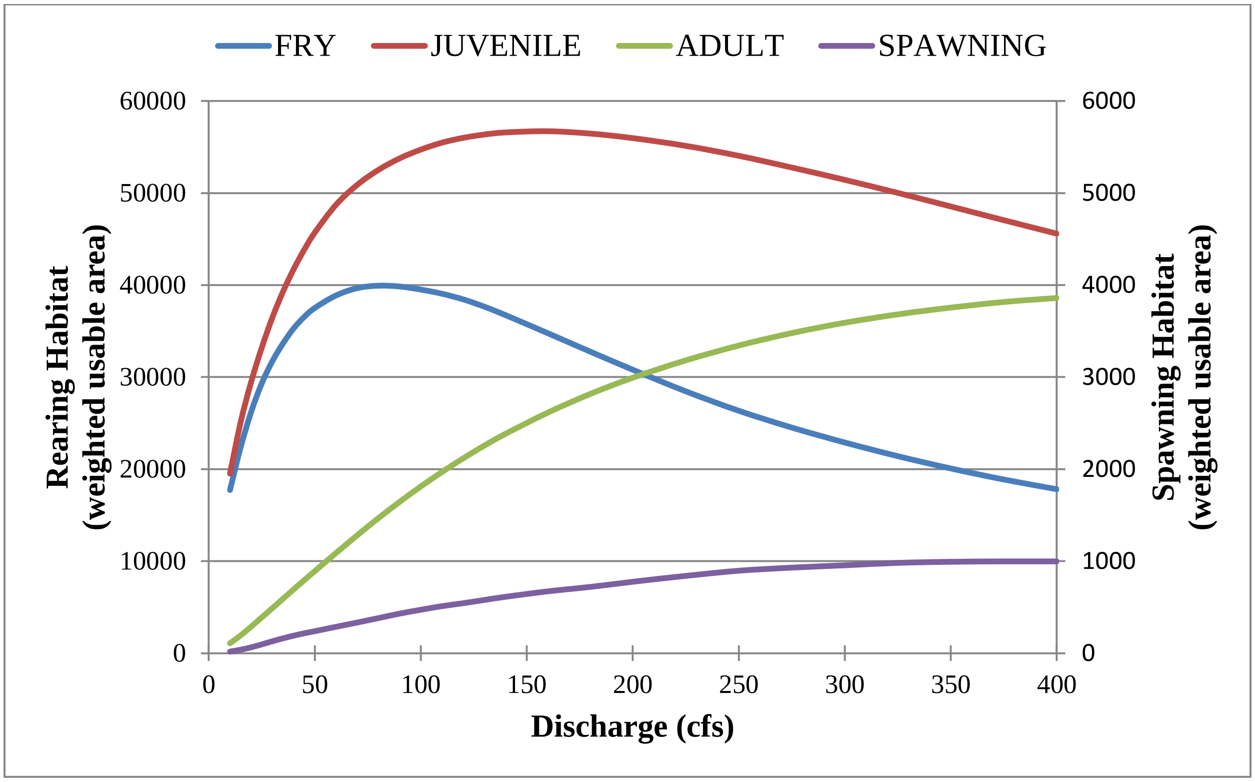


Figure 11. Weighted usable area vs. discharge for Redband Trout in the core area of the Crooked River. Reproduced with permission from Hardin (1993).

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