Appendix G

Warmwater Fish Methods for the Watershed Flow Evaluation Tool

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A report to the Non-Consumptive Needs Committee of the Colorado Basin Roundtable

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Summary and Recommendations

For the Watershed Flow Evaluation Tool Pilot Study (WFET; CDM et al. 2009), Wilding and Poff (2008) developed methods for evaluating risk to warmwater fish species resulting from water development and management that changes the timing and quantity of river flows. This current report incorporated feedback on the concepts presented in the 2008 report and more analysis was done, leading to modification of WFET methods for warmwater fish (Wilding and Poff 2008). The two most significant modifications are: (i) we are no longer recommending a Method 10 from Wilding and Poff for evaluation of the listed endangered Colorado pikeminnow; rather, we are incorporating U.S. Fish and Wildlife Service flow recommendations into the WFET, and (ii) the method for non-listed, at-risk warmwater fish species (flannelmouth sucker, bluehead sucker, and roundtail chub) was modified to a method based on data for the two suckers but not roundtail chub. Also, this modified sucker method was refined to apply only in specific geomorphic settings, was adjusted to eliminate potential conflating for flow effects and non-native predatory fish effects, and was validated using independent data..

Flow targets for endangered fish are drawn from documents available through the Upper Colorado River Recovery Program. For the Colorado River, the primary reference is the Programmatic Biological Opinion (PBO) for the 15-mile reach between Palisade and Grand Junction as well as supporting documents, especially Osmundson's 2001 report on flow regimes for restoration and maintenance of sufficient habitat to recover endangered Razorback Sucker and Colorado Pikeminnow in the upper Colorado River.

In this report we analyzed gaged flows at one location (Palisade, gage 09106150) compared to a subset of the 15-mile reach flow recommendations. This analysis of gaged flows for the period of record (water years 1991-2010) illustrates that flow recommendations are frequently not attained at this location. We present the results of this analysis as a relatively simple approach to using output from the state's surface water flow model (StateMod) to readily compare how multiple water management scenarios perform with respect to PBO flow recommendations. However, we do not suggest that this approach is a definitive statement as to how water management on the main stem is doing to achieve endangered fish flows in the 15-mile reach.

For bluehead sucker and flannelmouth sucker, a revised function is presented for evaluating the biological effects of long-term changes in flow:

% maximum native sucker biomass = 0.1026 x 30-day min flow$^{0.3021}$

where '30-day minimum flow' is a running mean) calculated over the summer-autumn flow period (1 July to 30 November) for each year, then averaged over the study period (1975-2005).

In this manner, biomass is estimated for both baseline (natural) conditions and a managed scenario (typically ‘current’ at a minimum). Percent reduction in biomass is then calculated as:

% reduction in biomass = (baseline – current) / baseline)

Risk classes based on expert recommendations are: low risk (0-10% reduction in biomass), minimal risk (10-25% reduction), moderate risk (25-50% reduction), and high risk (50-100% reduction).

Flannelmouth and bluehead sucker are warmwater fish, so it is important that the method is not applied where cool water temperatures may override the flow response. Therefore the sucker method should only be applied at nodes below 7,000 feet elevation. More specific limits can be specified for the mainstem of the Colorado River - Radium at 6,850 ft (downstream of USGS 09058030). Likewise, on the Roaring Fork River a specific upstream limit at the Frying Pan confluence is recommended (6,590 ft). Within this temperature envelope, application of the sucker method should be further constrained to exclude low energy reaches (channel slope <0.1%) to focus on reaches with more suitable habitat (rocky substrate).

The use of low flows to indicate sucker response was supported by spatial validation analysis using independent catch data from the Colorado basin. Sucker monitoring data from the San Juan River demonstrated that sucker populations do not follow inter-annual flow fluctuations. The sucker method therefore describes change in carrying capacity over longer periods, rather than year-to-year variability.

Introduction

The purpose of this section is to review the flow-ecology relationships for warmwater fish that were developed by (Wilding and Poff 2008). Specifically, where in the upper-Colorado basin should the methods be applied and do the relationships hold if validated against independent datasets? This report focuses on Method 9 from (Wilding and Poff 2008), which describes the relationship between low flow and potential biomass of bluehead sucker, flannelmouth sucker and roundtail chub. The flow metric used to describe low flows was revisited for this report using additional flow metrics that were not included in the source document (Anderson and Stewart 2007). The potential to describe the flow-ecology response for all three species using one method was also investigated (compared to 3 equations for Method 9). Alternative methods for Colorado pikeminnow are also reviewed.

Endangered fish of the 15-mile reach

Four species of fish that are listed as Endangered are affected by water management on the mainstem of the Colorado River: Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub (*Gila cypha*), bonytail (*Gila elegans*), and razorback sucker (*Xyrauchen texanus*). However, only the Colorado pikeminnow and razorback sucker are currently known to occur in the 15-Mile Reach. The PBO (US FWS 1999) reviews the critical aspects of the biology and ecology of these species as well as the importance of the 15-mile reach to Colorado pikeminnow and razorback sucker.

Flow-ecology methods for endangered fish in the 15-mile reach

Wilding and Poff (2008) developed a generalized flow-ecology relationship for Colorado pikeminnow that they referred to as Method 10. The U.S. Fish and Wildlife Service (US FWS 1999) presents specific flow recommendations for endangered fish were presented for the 15-mile reach (Figure 1) in the Programmatic Biological Opinion. These specific recommendations

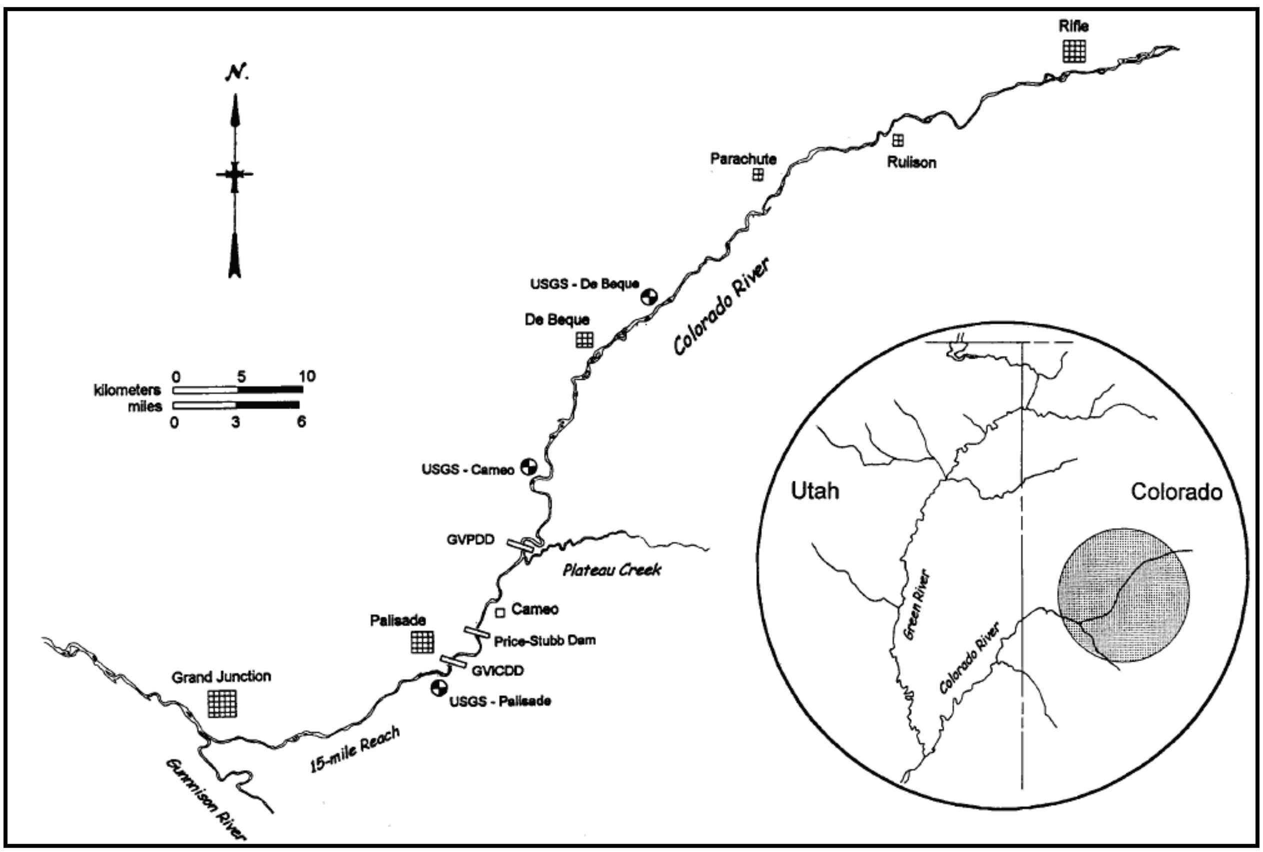


Figure 1 Reproduced from (Osmundson 2001), this map shows the 15-mile reach between Palisade and Grand Junction where endangered fish management is focused, plus the reach extending to Rifle where improved fish passage might restore populations as far upstream as Rifle.

(reproduced in Tables 1 and 2 below) were based on extensive research by scientists with detailed knowledge of these species and their habitats (e.g., Osmundson et al. 1995)—including research in the 15-mile reach—and they represent the best available science on flow needs of the endangered fish in this river segment. As such, we are no longer referencing Method 10. We have instead used the PBO recommendations to illustrate the status of flows as compared to the recommendations. There is one StateMod node within the 15-mile reach (09106150) and flow recommendations were specific to this same location, making it relatively easy to compare of gage and/or modeled streamflows with flows recommended for endangered fish.

Flow recommendations are expressed in the PBO (US FWS 1999) as (i) target peak day spring flows (PBO Table 1), (ii) recommended mean monthly flows for four different exceedance values, and (ii) volumes of water needed per 10-day period to achieve spring flow targets. It was beyond the scope of this effort to assess the status of current flow relative to this full set of recommendations. However, we did want to compare current conditions with some aspects of these recommendations with the intent of offering a relatively simple approach to quickly ascertaining how a given flow scenario performs relative to these recommendations. Specifically, do current conditions in the 15-mile reach meet recommended conditions? To assess this question, we focused our analysis on a subset of the recommendations, representing the highest and lowest flow conditions. Specifically, we focused our analysis on spring flow targets, mean flows for June flows (the month with the highest targets), and mean flows for August through October (the months with the lowest targets).

The “current” record we assessed was 20 years of gage data (WY1991-2010) from USGS 09106150 COLO RIVER BELOW GRAND VALLEY DIV NR PALISADE, CO. For our analysis, we compared actual exceedance values to those recommended in the PBO. The results of this analysis (Figure 2) demonstrate that the occurrence of flows exceeding the recommendations (US FWS 1999) were the exception, rather than the rule.

The construction of fish passes over several diversion dams has restored access between Palisade and Rifle as of 2008 (RIPRAP 2009). This then raises the question of flow response at other nodes, including De Beque Canyon (Cameo node 09095500) and the alluvial reach between De Beque and Rifle (De Beque node 09093700). Flow requirements for this Palisade to Rifle reach were investigated by Osmundson (2001). Final recommendations for spring flows were provided, and closely match those for the 15-mile reach because of similar bankfull flows. The author was limited to interim recommendations for summer flow due to data constraints, but these were also similar to the 15-mile reach. Achieving the flow recommendations for the 15-mile reach would, in most instances, exceed the flow recommendations for the Palisade to Rifle reach because of the large water diversions above Palisade. So, in order to simplify analysis and reporting, flow metrics are only reproduced here for the 15-mile reach with the expectation this will adequately represent flow constraints for pikeminnow in the upper Colorado basin. Readers interested in the realization of flow recommendations for the Palisade-Rifle reach are referred to Osmundson (2001) for detailed comparison of current flow conditions at Cameo to recommended flows for endangered fish (available at http://cwcbweblink.state.co.us/WebLink/DocView.aspx?id=133033&page=1&dbid=0).

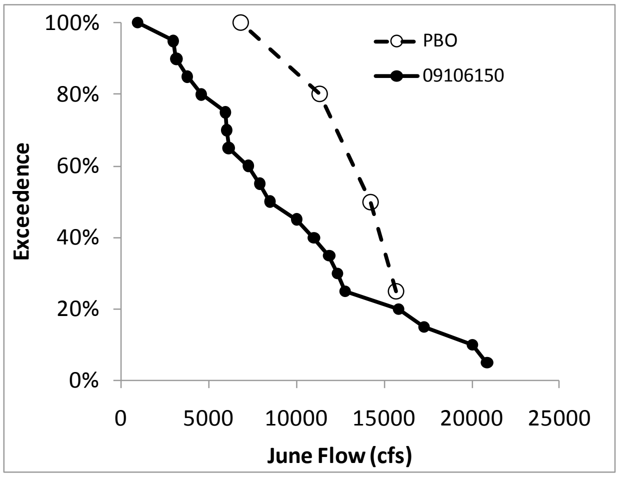
Table 1 Target peak daily spring flows in the 15-mile reach (Palisade to Grand Junction) of the Colorado River. These are specified in (US FWS 1999) to support endangered Colorado pikeminnow and razorback sucker.

Peak flow (cfs)	Return period
>23,500	5 in 20 years
21,750	10 in 20 years
16,700	16 in 20 years
12,900	20 in 20 years

Table 2 From (US FWS 1999), “recommended mean monthly flows for the top of the 15-Mile Reach in cubic feet per second. Rate is the percent of years recommended for identified flows based on winter snowpack levels. For example, in the wettest 25 percent of years, flows in June should average at least 15,660 cfs; stated another way, this recommendation should be met in 5 of every 20 years. During low-water years, June flows should average no less than 6,850 cfs, and such a minimum should occur at a rate of no more than 4 in 20 years (20 percent).” To clarify, “Rate” is for a flow-interval (e.g. August flows should be between 810 and 1,240 cfs for no more than 20% of years) whereas “Exceedance” is cumulative (e.g. August flows should exceed 810 cfs for 100% of years). The rows we analyzed are in bold type.

Rate	25%	25%	30%	20%
Exceedence	25%	50%	80%	100%
JAN	1,630	1,630	1,630	1,240
FEB	1,630	1,630	1,630	1,240
MAR	1,630	1,630	1,630	1,240
APR	3,210	2,440	2,260	1,860
MAY	10,720	9,380	7,710	7,260
JUN	**15,660**	**14,250**	**11,350**	**6,850**
JUL	7,060	5,370	3,150	1,480
AUG	**1,630**	**1,630**	**1,240**	**810**
SEP	**1,630**	**1,630**	**1,240**	**810**
OCT	**1,630**	**1,630**	**1,240**	**810**
NOV	1,630	1,630	1,630	1,240
DEC	1,630	1,630	1,630	1,240

(a)



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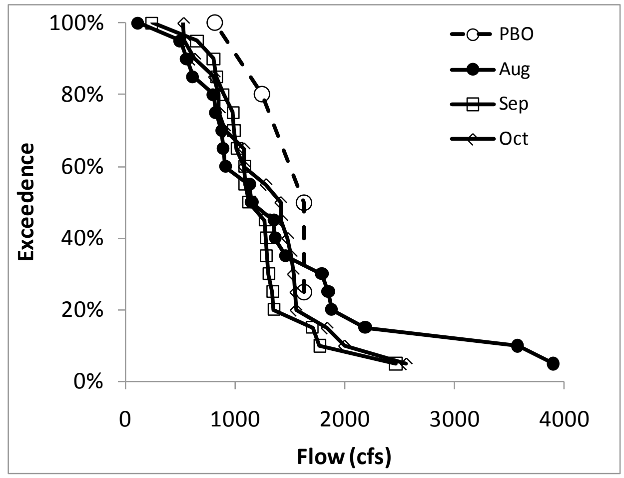

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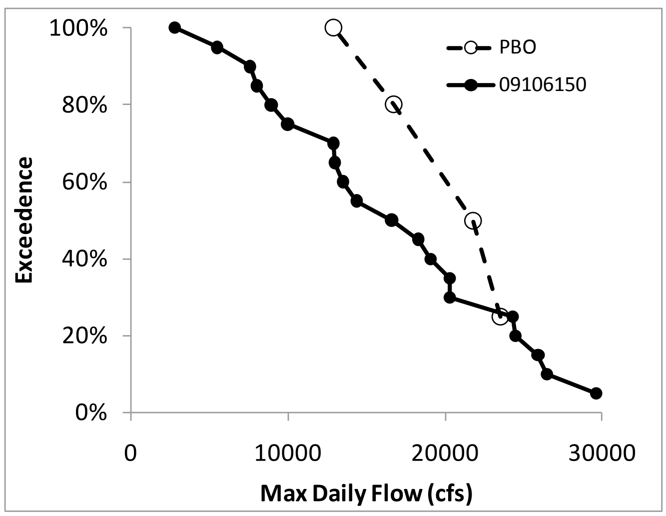

Figure 2. Exceedence of current flows (WY1991-2010) to flows recommended in the Programmatic Biological Opinion (PBO) for endangered fish at Palisade (US FWS 1999) using observed gage data: (a) mean flows for June, (b) mean flows for August, September, and October, and (c) annual maximum daily flows (Oct-Sep water year).

Non-listed warmwater fish

Wilding and Poff (2008) developed flow-ecology relationships for three other native warm-water species: roundtail chub, flannelmouth and bluehead sucker. All three species are the subject of a multi-state, rangewide conservation agreement (UDWR 2006). The roundtail chub is a Colorado state species of concern. The relationships developed in 2008—which approached each species separately—were revisited with the intent of develop a single relationship that could represent all three species (species-specific functions were presented in Wilding and Poff 2008 as Method 9). Firstly, it is worth reviewing the biology of these three species to be able to assess common responses to habitat conditions among the species. The following descriptions were adapted from Wilding and Poff (2008), with information added for this report on habitat and diurnal behavior.

*Biology of bluehead sucker (***Catostomus discobolus***)*

This species feeds on benthic algae and invertebrates. It is most commonly found in rocky riffle habitat (Ptacek et al. 2005), and has been observed at flow velocity of 0.4-1.4 m/s and depths of 0.3-1.5 m (Stewart and Anderson 2007, Bower et al. 2008). Daytime and nighttime habitats are similar (Beyers et al. 2001). The bluehead sucker matures at 4-6 years and >300 mm length in large rivers, 150 mm in small rivers, with some adults aged in excess of 20 years (Ptacek et al. 2005, Bower et al. 2008). Spawning benefits from high flow (Apr-July) and a low to moderate number of degree days (Muth and Nesler 1993).

Biology of flannelmouth sucker (Catostomus latipinnis)

This species feeds on benthic algae and invertebrates. It is a habitat generalist (Martinez et al. 2001, Rees et al. 2005a), and has been observed at flow velocity of 0.5-0.9 m/s and depths of 0.5-2 m (Stewart and Anderson 2007, Bower et al. 2008). Daytime and nighttime habitats are similar (Beyers et al. 2001, Rees and Miller 2001). The flannelmouth sucker matures at >400 mm length in large rivers, 200 mm in small rivers, and it can live for 30 years (Rees et al. 2005a, Bower et al. 2008). Spawning benefits from high flow (Apr-July) and a low to moderate number of degree days (Muth and Nesler 1993).

Biology of roundtail chub (Gila robusta)

This species feed opportunistically throughout the water column on plant matter, invertebrates and fish (Rees et al. 2005b). Daytime habitat of adults includes deep, low-velocity habitats with cover (Rees et al. 2005b), with increased use of shallow habitats at night (Beyers et al. 2001).

Comparing the three species, both suckers consume similar food but feed in different areas. Bluehead suckers are scrapers that are generally associated with cobble substrates, compared to flannelmouth suckers that feed on smaller substrates, including silt. Flannelmouth suckers are found in slower water than bluehead but, because greater depths are occupied by flannelmouth, the flows needed to produce suitable habitat may approach that of bluehead. For roundtail chub, their diurnal shift complicates direct comparison of habitat use. The diet and diurnal habitat use of adult roundtail chub implies active hunting behavior more like Colorado pikeminnow than the suckers. Roundtail chub were historically found at higher elevations than pikeminnow and lower elevations than cutthroat habitat.

Distribution

The distribution of the three species was reviewed in detail by (Bezzerides and Bestgen 2002) and the report, complete with distribution maps, is available at http://warnercnr.colostate.edu/larval-fish-lab-contributions/. The three species are confined to Western Slope streams and were commonly and recently collected from the mainstem Colorado River below Rifle. Historically, flannelmouth and roundtail were found farther upstream at least as far as Glenwood Springs, with bluehead sucker reaching Parshall (Bezzerides and Bestgen 2002). There are recent records of both flannelmouth and bluehead sucker further upstream than Rifle, including Dotsero on the Colorado River (Deacon and Mize 1997), the lower Eagle River (Woodling and Albeke 1999), and from the Roaring Fork below the Frying Pan confluence (Miller 2002).

Based on these distributions, we recommend limiting application of the flow-ecology methods for sucker in the upper Colorado basin to nodes below 7,000 feet elevation. More specific limits can be specified for the mainstem of the Colorado River - Radium at 6,850 ft (downstream of USGS 09058030). Likewise, on the Roaring Fork River a specific upstream limit at the Frying Pan confluence is recommended (6,590 ft). Suckers are likely present at higher elevations, but the cutoff is intended to constrain application of flow-ecology methods to sites where temperature is less likely an overriding constraint.

Flow-ecology methods for chubs and suckers

The same dataset used by Wilding and Poff (2008) was reanalyzed for this report. Anderson and Stewart (2007) gathered fish data across a wide range of flow conditions, representing gradients of flow modification, inter-year and site variability, using comparable methods. Sites included the Yampa, upper-Colorado, Gunnison and Dolores Rivers (see aerial photos Appendix 1). Mark-recapture raft electric fishing was carried out for all sites to estimate biomass per unit area (kg/ha). By employing data from rivers where temperature was not a major limiting factor, it was possible to distinguish the effects of flow. The four rivers have adequate summer temperatures for warm water fishes, and so provide a better depiction of flow response when temperature is not an overriding issue. The Gunnison is the most regulated of the four rivers, but the study reaches were far enough downstream of dams for temperatures to exceed 18 °C in summer (daily average, U.S. Fish and Wildlife data).

Comparing the observed response to low flows, the three species are broadly similar (Figure 3), with generally increase % of maximum biomass as low flows increase. The two suckers are comparable, with the smaller bluehead sucker possibly benefiting more at lower flows (<500 ft^3/s). By comparison, Stewart and Anderson (2007) predicted bluehead to have higher flow requirements than flannelmouth. The response of roundtail chub to low flow was variable, with only a few site/years with >50% of maximum biomass. These few sites also fall short of the maximum biomass observed for the suckers (maximum 40 kg/ha for roundtail chub compared to 348 kg/ha for bluehead sucker and 180 kg/ha for flannelmouth sucker). There is not enough data to confidently claim the sucker relationship is representative of the flow response for roundtail chub. There are also important differences in feeding and habitat use by roundtail chub that might produce a divergent flow response. Subsequent analysis therefore excluded roundtail chub, instead using combined biomass of bluehead and flannelmouth suckers (% of maximum biomass) to provide a single response function representative of the suckers.

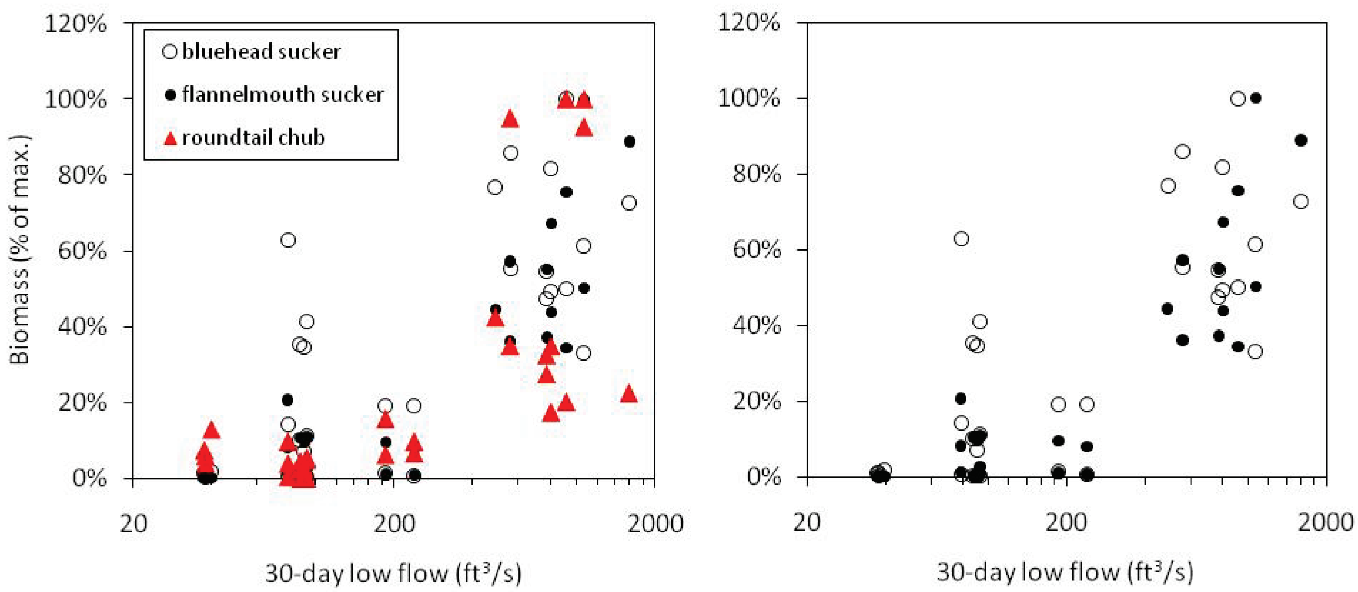

Figure 3 Comparing the response of the 3 fish species to low flow. Roundtail chub, bluehead and flannelmouth sucker are presented in left plot, with the right plot focusing on the two suckers for clarity. Data are sourced from Anderson and Stewart (2007). Fish biomass was measured in kilograms per hectare, and subsequently standardized by the observed maximum for this analysis. Low flow is quantified as the minimum 30-day moving average flow for July-November.

The WFET Pilot (CDM et al. 2009) used flow metrics provided by Anderson and Stewart (2007) and these were revisited using alternative flow metrics calculated from the same gages to determine which metric can best predict biomass response, with particular emphasis on metrics that are confidently calculated using StateMod model (based on daily time series). Using Indicators of Hydrologic Alteration (IHA; Richter et al. 1996) software, short-term flow minima (1, 3 and 7 day running mean) and extended minima (30 and 90 day) were calculated for the summer-autumn period (1 July to 30 November). It was necessary to isolate the low-flow season because low flows can occur at any time of year in the more regulated rivers and the summer-autumn minima also had the advantage of being better predictors compared to winter minima. Anderson and Stewart (2007) also used seasonal minima instead of annual minima presumably for the same reasons. The 7-day minima should be less sensitive to outliers than the 1-day minima used in the original WFET report, and gave a similar response (Figure 4). The 30-day minima produced a higher R^2 value than the pre-sampling 60-day average used by Anderson and Stewart (2007) (Figure 4). The use of a pre-sampling average flow is not directly applicable to future flow scenarios as we are not concerned with any specific date. All functions use Log_{10} transformed values of absolute flow, and the correlations were not improved using specific discharge (flow/watershed area).

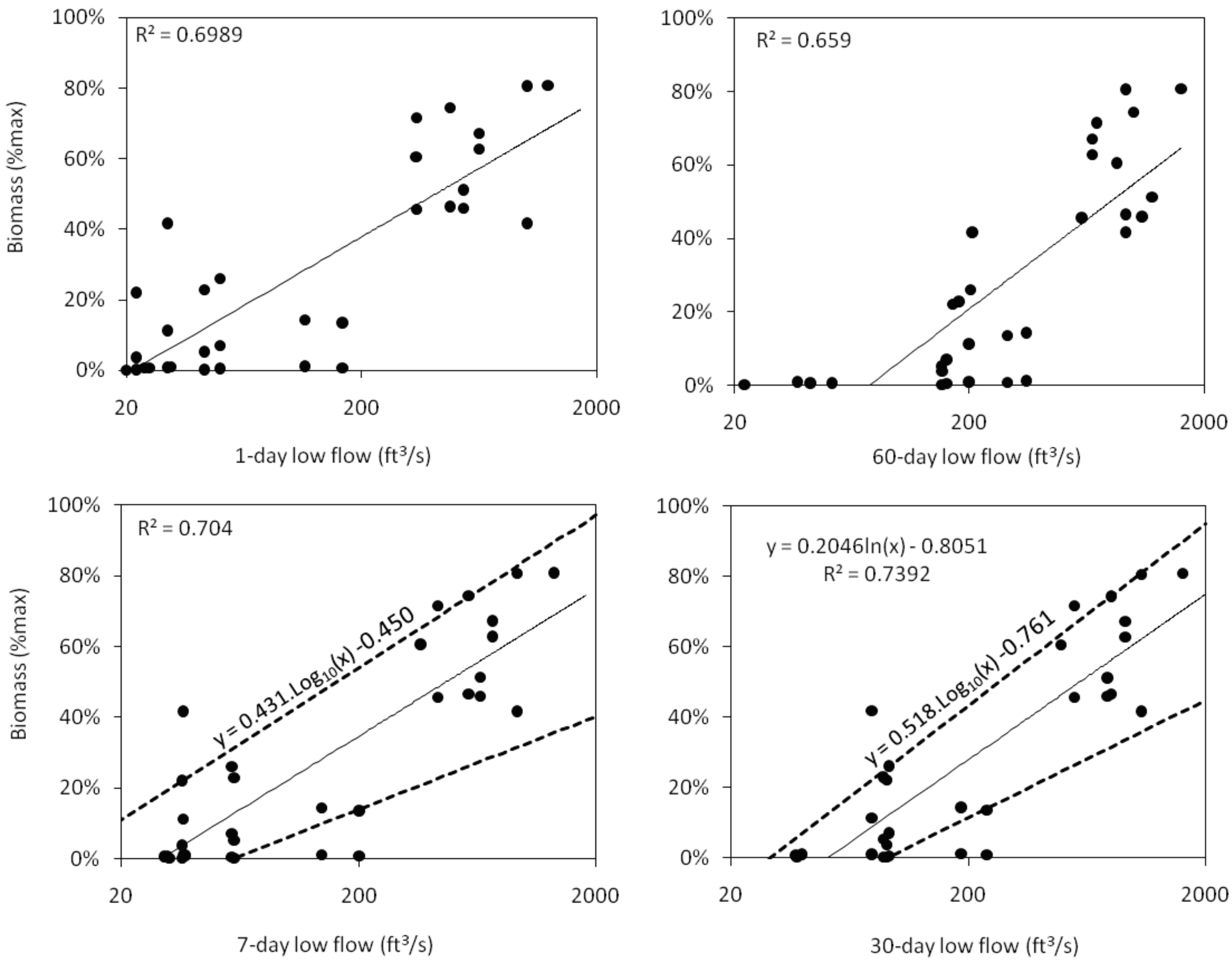

Figure 4 Comparison of response to four flow metrics by fish biomass (% of max. across all site/years) averaged for flannelmouth and bluehead sucker (each point is a site-year estimate). The top two plots use flow metrics sourced from Anderson and Stewart (2007) with the "60-day low flow" averaged over the 60 days prior to fish sampling (as per Wilding and Poff 2008). The lower two plots are the minimum running mean (7 and 30 day) during summer/autumn (1 July to 30 November). The R^2 values relate to the mean response (least squared regression), and quantiles are also fitted (using least absolute deviation) to the lower plots (10% and 90%ile, p<0.1 and <0.01 respectively) with equations given for the 90%ile (upper bound).

Although the above results (Figure 4) show a relationship between minimum flows and individual site-year values, it is more useful to consider biological response to long-term flow changes (e.g. contrasting 25 years with and without diversions). The long-term is of more interested because bluehead and flannelmouth suckers are long-lived fish (Ptacek et al. 2005, Rees et al. 2005a), and so the population observed any one year is a product of complex population dynamics over preceding years. We increased the temporal scale by averaging the annual monitoring data over a longer time step (in the absence of a population dynamic model for every reach in Colorado, we instead treat year to year variation as stochastic). The biomass data for each site were divided into two groups - a dry period (2002-2005) and a period of above average flows (1997-2001)[1], with flow averaging extending back an additional three years. The units of biomass were also changed from area based (kg/ha) to river-length based (kg/km) because standardizing by area (hectares in this case) factors out an important aspect of flow dependence - area increases with flow (temporally and spatially). This conversion was calculated using the flow for each sampling date and the relationships between surface area and flow (derived using Table II-4 from Anderson and Stewart 2007).

These refinements clarified the flow response for suckers. Considering only the temporal component, the dry-period biomass of suckers was less than the wetter-period biomass for all sites (paired t-test p-value 0.03 performed on averages, except the Gunnison which lacked pre-drought biomass data). Sucker biomass increased with flow both over time and between sites (Figure 5), though there remains some scatter about the mean response function (left plot). Researchers report higher numbers of sucker in rocky areas that provide stable substrate for algae and other food (e.g., Ryden 2001). This explains some of the variability in the flow response observed here. Specifically, the residuals from the mean flow response are positively correlated with channel slope (R^2 = 0.54, see footnote[2]), which is expected since more cobble riffles—which is better sucker habitat—typically occur in steeper reaches.

An additional source of variability is the suppression of sucker biomass by high densities of introduced fish. For example, the 2002 drought was associated with a dramatic increase in numbers of smallmouth bass in the Yampa River (Anderson and Stewart 2007, Bestgen et al.

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[1] For example, 30 day low flows for Yampa at Maybell averaged 208 ft^3/s for 1997-2001 compared to 76 ft^3/s for 2002-2005. Annual series statistics for the full record (1917-2009) include a 30%ile low flow of 113 ft^3/s and 70%ile of 226 ft^3/s.

[2] Multiple linear regression model: %max biomass (kg/km) = 0.2265.Ln(30 day min cfs) + 268.8.slope - 1.208. For N = 14, F-stat = 70.76, regression P-value < 0.001, Adjusted R^2 = 0.915. In this model, the P-value for the slope coefficient (268.8) was 0.001. Model would only apply to warmwater streams, as temperature is not included.

2007). Likewise, introduced fish may pose an important constraint on sucker biomass in the Dolores River (Anderson 2010). A second response function was therefore developed for the flow period dataset, which omits data points where substrate stability or introduced fish may be primary constraints on sucker biomass (dashed line, Figure 5). The slope threshold used for habitat suitability (sites excluded if slope <0.10%) aligns with the geomorphic classification used for the WFET (Bledsoe and Carlson 2010), distinguishing moderate-energy reaches from low-energy. The recommended flow-ecology method for sucker is:

$$\% \text{ maximum native sucker biomass} = 0.1026 \times \text{30-day low flow}^{0.3021}$$

This revised function acknowledges that factors in addition to flow may also constrain native fish populations in the Dolores and Yampa Rivers. Eliminating data collected where non-native fish are present also presumes that flow was not a primary mechanism for the impact of introduced fish.

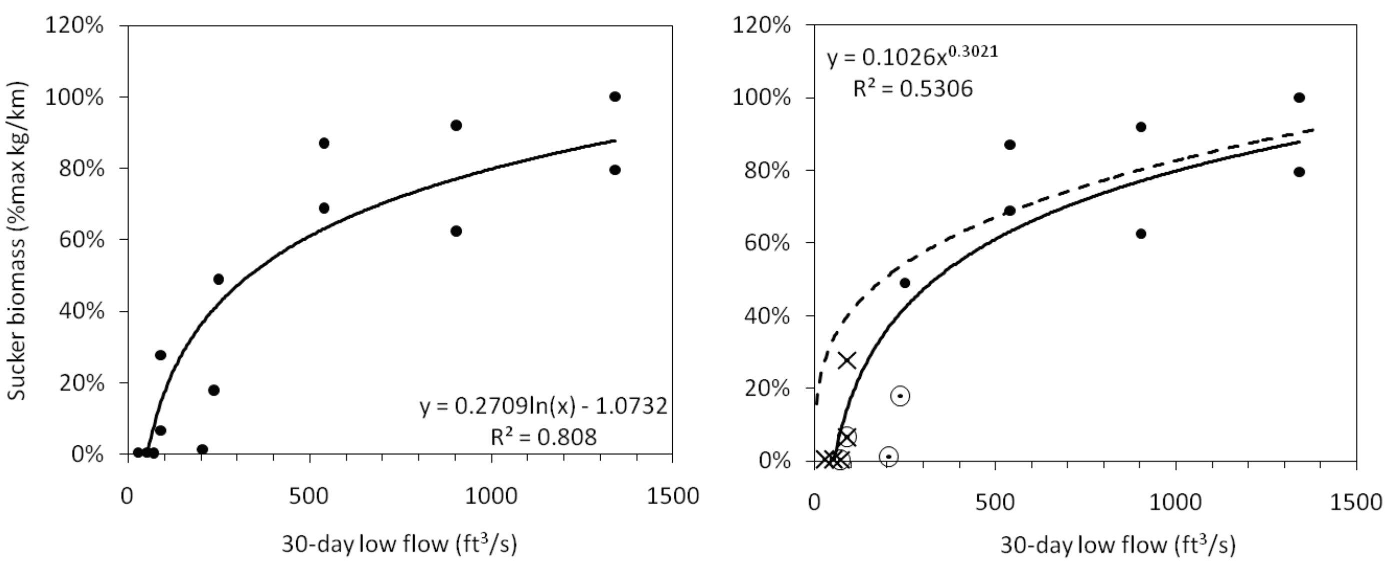


Figure 5 The response of sucker biomass to flow, increasing the temporal scale to flow periods (from years in previous plots). Each site is represented by just two points (average biomass pre- and post-2002 drought). The biomass units were changed from area based (kg/ha) to river length based (kg/km) to isolate biomass from changes in width with flow. The right plot differs from the left by circled data points for low energy streams (slope <0.10%) and crossed points where biomass may be suppressed by introduced fish (Yampa post 2002 and both Dolores periods). The dashed regression line describes the mean response for only steeper streams less impacted by introduced fish (ANOVA p-value <0.01 for both regression lines).

Sucker method validation

Validation of the sucker method employed two datasets – the first a spatial dataset (multiple sites sampled once), and the second a temporal dataset (repeat annual monitoring).

The first dataset describes abundance of suckers at 15 sites in the upper-Colorado basin (Deacon and Mize 1997). The flow metric (30 day minimum flow for July-November) was calculated from relevant StateMod nodes (for 4 sites) and USGS stream gages (for 11 sites). In three cases, the gage record did not cover the fish monitoring period, and so an extended record was synthesized from more distant gages with overlapping records. Stream temperature was reported by (Deacon and Mize 1997) and is used here as an alternative predictor to flow (they did not specify the duration of temperature monitoring). Abundance was measured as the number of fish caught per site, summed across bluehead and flannelmouth suckers.

The cold water streams draining the Rocky Mountains are expected to test the lower-thermal limits of suckers. Water temperature increased with flow ($R^2 = 0.32$) – the exceptions being four small streams at low elevations. The correlation clearly works in favor of sucker abundance (Figure 6) with higher abundance in warmer larger streams. Both variables are important and neither variable is adequate on its own to explain differences in abundance between sites. Residuals from the temperature relationship were still positively correlated with flow (Figure 7). Removing the temperature effect also produces a flatter response to flow that better matches the sucker method (Figure 7).

The sucker abundance metric (total number of suckers caught) is influenced by fishing effort which was not equal across sites (wadeable sites were electric fished over a 450-650 ft reach and nonwadeable sites boat-electric fished over a 1,500-3,000 ft reach). Site specific effort was not described by the authors, but presumably the five largest rivers were boat electric fished (these do not appear wadeable from aerial photos). The shortcomings of the abundance metric prevents development of a predictive model from this dataset, but adds weight of evidence in validating the flow-ecology relationship derived in this report using an independent dataset.

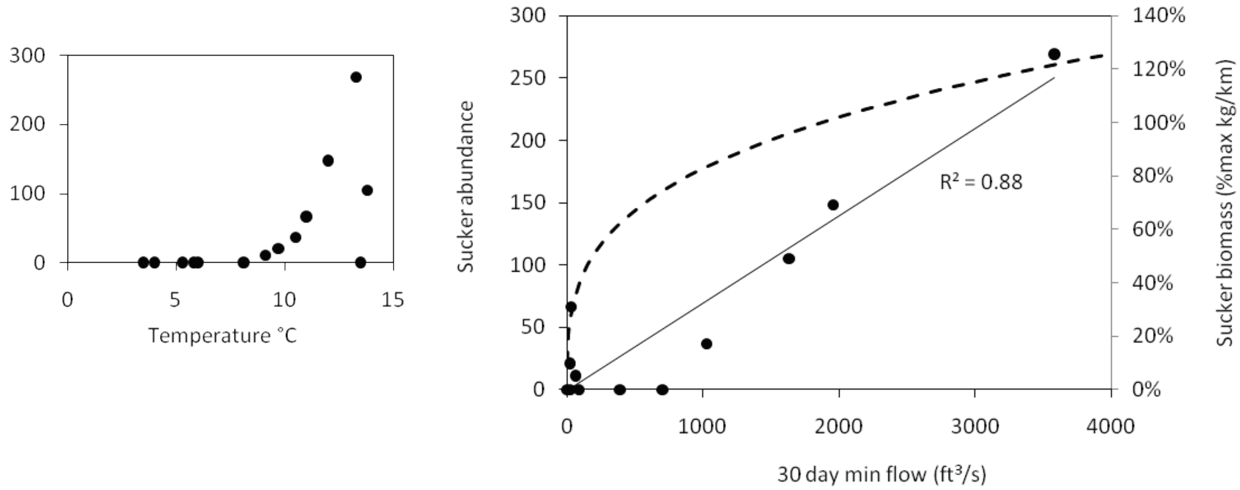


Figure 6. Association between suckers (bluehead plus flannelmouth) and flow for sites monitored by USEPA in the upper Colorado basin (Deacon and Mize 1997). The flow metric is the 30-day minimum for July-November, averaged over the sampling year and five-years prior. Abundance is the number of suckers caught. The dashed line is the sucker method from Figure 5 overlaid for comparison, with units on the right axis (%maximum biomass). Temperature is also plotted to the left as a co-determinant of sucker abundance.

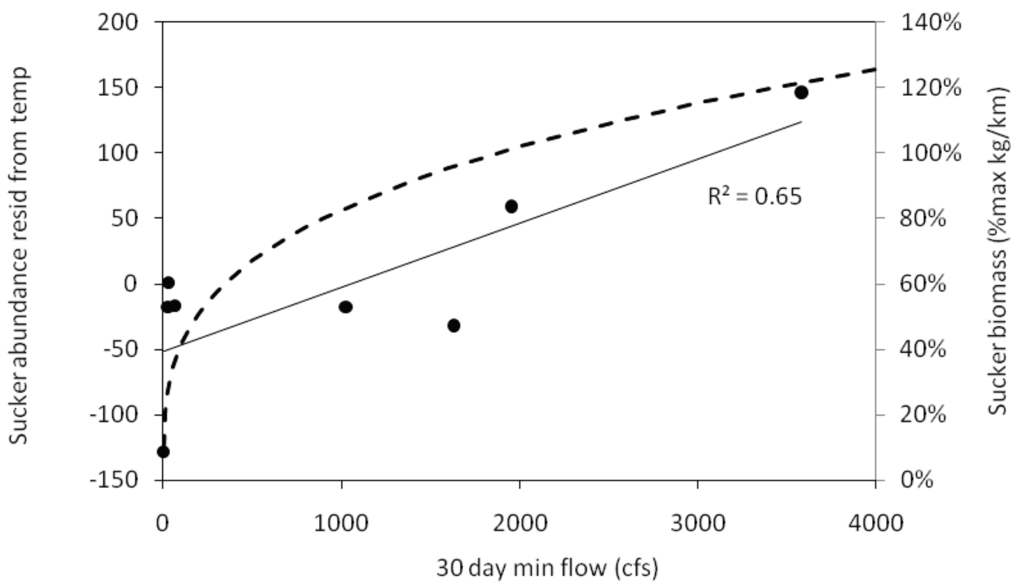


Figure 7. Residual flow response of sucker abundance after removing the effect of temperature. Only sites below 7,000 feet are presented (zero abundance at sites above this elevation). The dashed line is the sucker method from Figure 6 overlaid for comparison with units on the right axis (%maximum biomass kg/km). Otherwise as per Figure 6.

The second validation dataset describes changes over time for the sucker population of the San Juan River (Ryden 2010). The SJRIP (San Juan River Basin Recovery Implementation Program, www.fws.gov/southwest/sjrip) monitors fish populations annually for the mainstem San Juan River between the Animas River confluence and the Colorado River confluence (180 river miles). The suckers (bluehead in particular) are more abundant in reaches of the San Juan with more cobble substrate, notably Reach 6 below Farmington (channel slope 0.2%) (Ryden 2001). These stony reaches are assumed to drive interannual dynamics, despite using data from the extended monitoring area (180 river miles). Raft electric fishing data was analyzed by (Ryden 2010) to estimate CPUE (catch per unit effort - fish caught per hour) for the various species and size classes. For our validation analysis, CPUE data were extracted from the (Ryden 2010) report. Data for adult suckers (bluehead plus flannelmouth) were used in an effort to provide a better correlate of biomass than juveniles (the sucker method was developed from biomass data).

The number of adult sucker caught was not correlated with low flow (Figure 8). Populations of adult sucker were relatively stable over the monitoring period (1999-2009). Flows varied during this period, but in every year remained about 200 cfs. Changing from an annual time-step to flow periods that are more analogous to the flow periods used in the recommended sucker method also illustrates the stability of sucker populations in the San Juan. Using longer flow periods also illustrates that long-term low flows on the San Juan were also relatively stable during from 1999-2009. The monitoring results are therefore consistent with the sucker method which predicts little change in sucker populations in the absence of long-term reductions in flow, particularly at higher levels of flow (see dashed line in Figure 8).

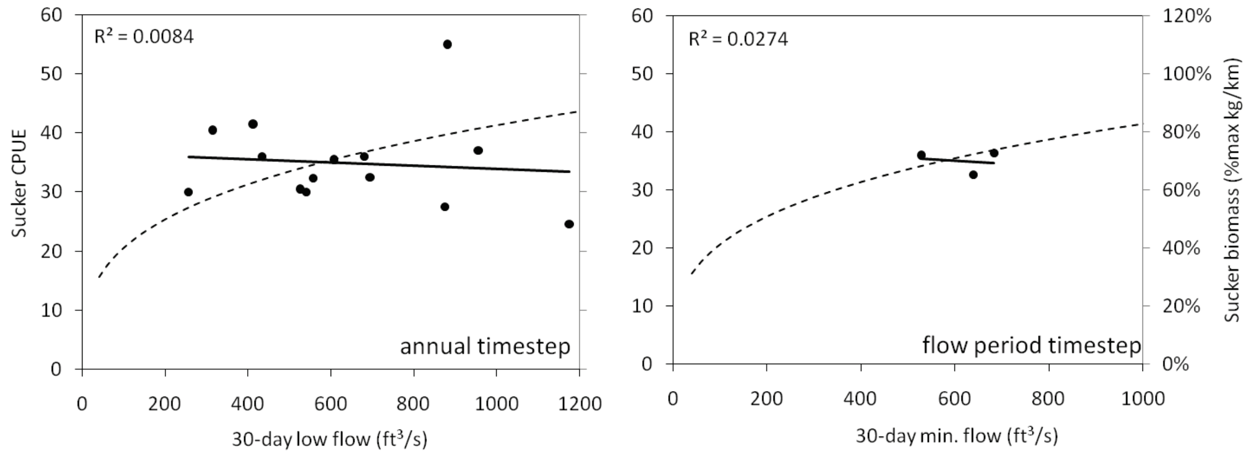


Figure 8

Correlation between number of suckers (bluehead plus flannelmouth) and flow for 180 miles of the San Juan River for the period 1996 to 2009 (data from Ryden (2010) and Ryden (2003)). The flow metric is the 30-day minimum for July-November at USGS 09371010 (Four Corners). The number of adult suckers (flannelmouth > 409 mm, bluehead >299 mm) caught per hour provides a standardized CPUE (catch per unit effort). The left plot presents annual monitoring results individually, and the right plot uses a longer time-step to represent flow periods (average 1996-01, 2002-04, 2005-09). The sucker method relationship is also presented (from Figure 6) as a dashed line using different units on the right y-axis (%maximum biomass).

Risk Classes for the Sucker Method

The sucker method can be used to contrast natural and altered flows, or other flow scenarios. Risk classes are recommended following input from fish experts based on the expected change in % maximum sucker biomass, as follows: low risk = 0-10% reduction in maximum biomass; minimal risk = 10 - 25% reduction; moderate risk 25-50% reduction; high risk = 50-100% reduction.

References

Anderson, C. 2010. Factors affecting populations of flannelmouth suckers on the Dolores River between McPhee Dam and the San Miguel River. *In* A. Oliver, C. Anderson, and R. Anderson, editors. Appendix B in "Baseline field investigations, science-based opportunities and potential tools for improvement of the downstream environment on the lower Dolores River". Colorado Water Conservation Board.

Anderson, R. M. and G. Stewart. 2007. Impacts of stream flow alterations on the native fish assemblage and their habitat availability as determined by 2D modeling and the use of fish population data to support instream flow recommendations for the sections of the Yampa, Colorado, Gunnison and Dolores rivers in Colorado. Colorado Division of Wildlife.

Bestgen, K. R., C. D. Walford, A. A. Hill, and J. A. Hawkins. 2007. Native fish response to removal of non-native predator fish in the Yampa River, Colorado. Larval Fish Laboratory, Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, CO.

Beyers, D. W., C. Sodergren, J. M. Bundy, and K. R. Bestgen. 2001. Habitat use and movement of bluehead sucker, flannelmouth sucker, and roundtail chub in the Colorado River. Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO.

Bezzerides, N. and K. Bestgen. 2002. Status review of roundtail chub *Gila robusta*, flannelmouth sucker *Catostomus latipinnis*, and bluehead sucker *Catostomus discobolus* in the Colorado River Basin. Colorado State University, Fort Collins, CO.

Bledsoe, B. P. and E. A. Carlson. 2010. A geomorphic valley classification for fluvial riparian areas.

Bower, M. R., W. A. Hubert, and F. J. Rahel. 2008. Habitat features affect bluehead sucker, flannelmouth sucker, and roundtail chub across a headwater tributary system in the Colorado River basin. Journal of Freshwater Ecology 23:347-357.

Camp Dresser & McKee Inc., B. Bledsoe, B. Miller, L. Poff, J. Sanderson and T. Wilding. 2009. Watershed Flow Evaluation Tool pilot study for Roaring Fork and Fountain Creek Watersheds and site-specific quantification pilot study for Roaring Fork Watershed. Draft report. Colorado Water Conservation Board. Denver, CO.

Deacon, J. R. and S. V. Mize. 1997. Effects of water quality and habitat on composition of fish communities in the upper Colorado River basin. USGS, Denver.

Martinez, P. J., B. M. Johnson, and J. D. Hobgood. 2001. Stable isotope signatures of native and nonnative fishes in upper Colorado River backwaters and ponds. The Southwestern Naturalist 46:311-322.

Miller, W. J. 2002. Fryingpan-Roaring Fork literature review. Fort Collins, CO.

Muth, R. T. and T. P. Nesler. 1993. Associations among flow and temperature regimes and spawning periods and abundance of young of selected fishes, Lower Yampa River, Colorado, 1980-1984 - Final Report. Colorado State University, Fort Collins.

Osmundson, D. B. 2001. Flow regimes for restoration and maintenance of sufficient habitat to recover endangered Razorback Sucker and Colorado Pikeminnow in the upper Colorado River:

Interim recommendations for the Palisade-to-Rifle reach. U.S. Fish and Wildlife Service, Grand Junction, CO.

Ptacek, J. A., D. E. Rees, and W. J. Miller. 2005. Bluehead sucker (*Catostomus discobolus*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region, Fort Collins, CO.

Rees, D. E. and W. J. Miller. 2001. Habitat selection and movement of native fish in the Colorado River, Colorado. Miller Ecological Consultants, Inc., Fort Collins, CO.

Rees, D. E., J. A. Ptacek, R. J. Carr, and W. J. Miller. 2005a. Flannelmouth sucker (*Catostomus latipinnis*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region.

Rees, D. E., J. A. Ptacek, and W. J. Miller. 2005b. Roundtail chub (*Gila robusta robusta*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region.

Ryden, D. W. 2001. Long term monitoring of sub-adult and adult large-bodied fishes in the San Juan River, 2000. U.S. Fish and Wildlife Service, Colorado Fish Recovery Project, Grand Junction, CO.

Ryden, D. W. 2003. Long term monitoring of sub-adult and adult large-bodied fishes in the San Juan River: 2002. U. S. Fish and Wildlife Service, Colorado River Fishery Project, Grand Junction, CO.

Ryden, D. W. 2010. Long term monitoring of sub-adult and adult large-bodied fishes in the San Juan River: 2009. U. S. Fish and Wildlife Service, Colorado River Fishery Project, Grand Junction, CO.

Stewart, G. and R. M. Anderson. 2007. Two-dimensional modeling for predicting fish biomass in western Colorado. Colorado Division of Wildlife.

UDWR (Utah Division of Wildlife Resources). 2006. Range-wide conservation agreement and strategy for roundtail chub *Gila robusta*, bluehead sucker *Catostomus discobolus*, and flannelmouth sucker *Catostomus latipinnis*. Prepared for Colorado River Fish and Wildlife Council. Salt Lake City, Utah.

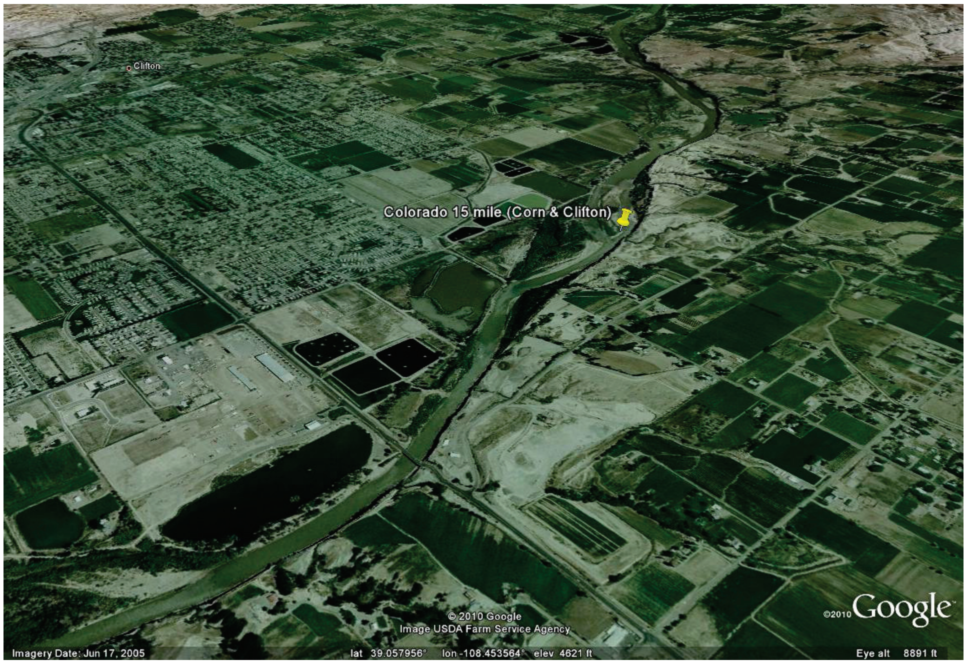
US FWS (U.S. Fish and Wildlife Service). 1999. Final programmatic biological opinion for Bureau of Reclamation's operations and depletions, other depletions, and funding and implementation of recovery program action in the upper Colorado River above the confluence with the Gunnison River. Fish and Wildlife Service, U.S. Department of the Interior, Denver, CO.

Wilding, T. K. and N. L. Poff. 2008. Flow-ecology relationships for the watershed flow evaluation tool. Colorado State University, Fort Collins.

Woodling, J. and S. Albeke. 1999. Annual biological assessment of the Eagle Mine Superfund Site, Eagle County, Colorado. Colorado Division of Wildlife.

Appendix 1 – Site Photos

Aerial photos from Google Earth of approximate locations fished by Anderson & Stewart (2007). This is intended to depict general reach morphology rather than precise fishing locations.




Yampa at Duffy
Image © 2011 DigitalGlobe
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Imagery Date: Sep 29, 2005
lat 40.427835° lon -107.851988° elev 6247 ft
Eye alt 11320 ft


Yampa at sevens
Image USDA Farm Service Agency
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Imagery Date: Jun 17, 2005
lat 40.498911° lon -108.308419° elev 5831 ft
Eye alt 10418 ft


Yampa at Lilly
Image USDA Farm Service Agency
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Imagery Date: Jun 17, 2005
lat 40.457293° lon -108.415092° elev 5626 ft
Eye alt 9950 ft


Gunnison at Delta
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Imagery Date: Mar 23, 2006
lat 38.742778° lon -108.123051° elev 4899 ft
Eye alt 10070 ft


Gunnison at Escalante
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Image USDA Farm Service Agency
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