Evaluate effects of flow spikes to disrupt reproduction of smallmouth bass in the Green River downstream of Flaming Gorge Dam

by

Kevin R. Bestgen
Larval Fish Laboratory
Department of Fish, Wildlife, and Conservation Biology
Colorado State University
Fort Collins, CO 80526
kbestgen@colostate.edu

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Executive Summary

Smallmouth bass *Micropterus dolomieu* is considered the most problematic non-native fish species in the upper Green River basin in terms of negative impacts on native fish populations and endangered fish recovery (Bestgen et al. 2008; Johnson et al. 2008; Breton et al. 2013; 2014; 2015). Management of smallmouth bass in the upper Colorado River basin presently employs mechanical removal of any life stages that are susceptible to capture, mainly with electrofishing gear. Although mechanical removal is effective, other approaches that target early life stages, coupled with mechanical removal of older life stages, may provide longer-lasting effects and ultimately, further reduce the negative impacts of smallmouth bass and enhance recovery of native fishes. Thus, a different control method is proposed that involves disruption of smallmouth bass reproductive success with flow spikes and water temperature alterations. Potential effectiveness of this approach is not well understood because few other studies have been implemented to effect reduced spawning success of smallmouth bass. Even though effectiveness has not been tested with a rigorous study, empirical data and observations indicate potential effectiveness of this approach and testing this hypothesis is merited because of potential links between smallmouth bass and the declining status of Colorado pikeminnow *Ptychocheilus lucius* and other rare native fishes in the Green River. Presented here is justification and means to conduct studies to use flow spikes and water temperature reductions to disadvantage smallmouth bass reproductive success and reduce their abundance. Flow spikes and water temperature reductions are hypothesized as possible negative effects on bass based on a review of existing literature and on observations from natural events in locations such as the Yampa and Green rivers. For example, naturally occurring thunderstorms in those systems produced higher flows and turbidity that reduced survival of bass early life stages (Bestgen and Hill 2016a). Recommendations are offered on flow year type, frequency within and among years, and magnitude, duration, and timing of flow releases that may be effective to reduce bass abundance in the regulated reach of the Green River just downstream of Flaming Gorge Dam, as well as in the partially regulated Green River reach downstream of the Yampa River. Temporal sequencing of other flow management actions at Flaming Gorge Dam within a year was also considered and it was concluded that in most years, flow spike management will fit well in the context of annual operations. Those other flow management activities include provision of high flows in spring for enhanced floodplain connectivity to promote survival of razorback sucker larvae, and baseflow management in summer to enhance survival of young Colorado pikeminnow. Recommendations to evaluate effects of flow spikes, including assessments of physical habitat, and evaluation of distribution and abundance of smallmouth bass as well as native fish in pre- and post-flow-spike environments are also made. Other monitoring (i.e., invasive woody plants) is also discussed. This general framework for monitoring smallmouth bass spawning disruption may also be modified to evaluate flow or turbidity spikes to reduce impacts of smallmouth bass elsewhere in the upper Colorado River basin. Designed flow releases from reservoirs are offered as a legitimate means to combat invasive species and could yet another tool for managers to improve the status of rare and endangered fishes in the upper Colorado River basin.

Key words: management, control, piscivory, invasive species, regulated flows, water temperature reductions, native and endangered fishes, upper Colorado River basin, Green River, Yampa River

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Study justification and components of the flow spike study

The negative effects of flow disturbances, water temperature reductions, and increased turbidity on smallmouth bass hatching and recruitment are well known in the literature (Larimore 1952; 1975; Pflieger 1966; 1975; Reynolds 1990; Reynolds and O'Bara 1991; Lukas and Orth 1995; Peterson and Kwak 1999). Modeling of smallmouth bass population dynamics in upper Colorado River systems such as the Yampa River (Breton et al. 2015) showed that the single best means to reduce populations is reducing abundance of early life stages, including via disruption of reproduction. Reducing smallmouth bass survival and abundance over a series of years will ultimately limit recruitment of the species and reduce negative effects on native fishes.

Here I offer a suite of proposed physical and biological investigations to better understand effects of flow and water temperature alterations that are designed to reduce reproductive success and survival of young smallmouth bass in the Green River downstream of Flaming Gorge Dam (e.g., Figures 1 and 2; Bestgen et al. 2018). I offer recommendations for timing within a year for smallmouth bass disturbance flows, as well as how other flow management activities could be temporally staggered within a single year to benefit native fishes. Such actions offer management agencies another tool to achieve a more naturally functioning river ecosystem and enhance recovery of native biota, with potential benefits spanning extensive river reaches.

Overlap of flow releases for fish management, Green River.—Multiple requests for flow releases from Flaming Gorge Dam for various purposes creates a need to consider the temporal schedule of these events to ensure that detrimental overlap of desired flows does not occur. Flow releases already occur in spring during the peak or just post-peak of Yampa River snowmelt flows (Figure 3). This program, the Larval Trigger Study Plan (LTSP, LaGory et al. 2012), uses releases of water in spring to connect floodplain wetlands with the Green River at a time when razorback sucker larvae are present, and allows early life stages to rear in relatively warm and food-rich environments. Fast growth of larvae in summer increases the likelihood that young razorback suckers will survive and perhaps recruit to adult life stages, a rare event in the wild (Bestgen et al. 2011a; Webber et al. 2013; Recovery Program annual reports, http://www.coloradoriverrecovery.org/documents-publications/technical-reports/technical-reports.html, Project FR-165). The flows implemented under the LTSP have been successful to entrain larvae into floodplain wetlands each year from 2012-2018, and in 2013-2016 over 4,000 juveniles were produced from a single wetland, Stewart Lake (Recovery Program annual reports, http://www.coloradoriverrecovery.org/documents-publications/technical-reports/technical-reports.html, Project FR-165). That number of juveniles far exceeds the number known from all previous upper Colorado River basin studies ever beginning in the early 1960's, and thus, is considered a success, pending recruitment of some juveniles to the adult life stage.

Another flow release strategy to benefit young Colorado pikeminnow growth and survival in backwaters of the Green River downstream of the Yampa River was recently proposed (Bestgen and Hill 2016b; Grippo et al. 2017). This involves managing baseflows after LTSP flows later in summer. Specifically, baseflows in a range of about 48-85 m^3/sec (1,700-3,000 ft^3/sec) were consistent with higher levels of age-0 pikeminnow juveniles in autumn in the Green River since 1979 (Bestgen and Hill 2016b). Baseflows were thought especially important since about 2000, when extended drought-reduced flows, although in some years, baseflows may be reduced. Reduced recruitment of age-0 Colorado pikeminnow is consistent with reduced abundance of adults in the Green River basin, and more robust year classes are needed to stabilize those populations, the largest that remain in the wild (Bestgen et al. 2007a; Bestgen et al. 2010). Because flow spike management of smallmouth bass will occur between spring floodplain flows and summer backwater habitat management flows, and the few potentially confounding overlaps of actions are discussed below.

Baseline flow spike characteristics and conditions.—To assist the reader with understanding the scheduling and considerations of when and how to conduct a flow spike in the Green River downstream from Flaming Gorge Reservoir, I offer an overview and flow chart of actions (Figure 4) and a brief description of steps to consider in the following paragraph. I follow with an in-depth description of considerations and justifications for each step in the process. Finally, I discuss potential modifications to the plan based on observations from studies as they proceed. Text boxes alert the reader to the major components of the study design.

Each spring the Flaming Gorge Technical Work Group (FGTWG) will discuss implementation of a flow spike, which will initially occur in average or lower Green River hydrologic conditions. Average flow years on the higher end of the range should be given special scrutiny to ensure high likelihood of

> **Flow spike study component**:
>
> Convene FGTWG in spring to discuss flow spike feasibility

success. Other considerations include the type of flow year in the Yampa River, and reproduction timing by Colorado pikeminnow and other fishes, where a low or average flow year will encourage use of a flow spike, while a higher flow year will generally be avoided. Once the decision is made to implement a flow spike, empirical data including real-time observations and past data will be used to predict timing of onset of smallmouth bass hatching in the system. Observations of bass reproduction and habitat assessments prior to the flow spike period will occur if needed. About two weeks after first reproduction, when first larvae are hatched and most other eggs are deposited in nests, Flaming Gorge Dam flow releases will increase as quickly as possible to powerplant capacity, about 127.4 m^3/sec (4,500 ft^3/sec), and that flow will be maintained for three days. That flow level is needed to inundate side channel habitat where bass spawn, whereas at lower flow levels (e.g., 70.8 m^3/sec [2,500 ft^3/sec]), spawning is still successful (e.g., 2011, Bestgen and Hill 2016a). Monitoring of habitat connections and locations where bass are known to spawn will occur during that time. After three days of higher releases, flows will drop as quickly as possible. In the baseline plan, only a single flow spike will occur each year. Post-flow spike monitoring will then begin, and continue into autumn, using a variety of metrics, and effects of the flow spike on YOY smallmouth bass distribution and abundance will be assessed. Other programs will monitor effects of flow spikes on issues such as nonnative shrub vegetation proliferation and channel width change. Flow spikes will be implemented for a minimum of five years, not necessarily in consecutive years (appropriate hydrology may not occur five years in a row), to evaluate the utility of the technique to reduce smallmouth bass abundance in the Green River. A summary report will be prepared based on those five annual efforts, which will guide future implementation of flow spikes, including whether the study should continue.

Detailed considerations and descriptions of flow spikes.—Flow and temperature disturbance of Green River smallmouth bass reproduction is possible through managed releases from upstream Flaming Gorge Dam. Disturbances should be focused in both the regulated reach of the Green River upstream of the Yampa River (regulated reach), as well as in the partially regulated reach of the Green River, just downstream of the Yampa River (partially regulated reach; Figure 2).

Smallmouth bass life history attributes enhance the likelihood that flow disturbances will reduce reproductive success (Winemiller and Taylor 1982; Peterson and Kwak 1999). Male bass construct nests in low velocity stream habitat, usually channel margin backwaters or cutoff secondary channels, by fanning fine sediment to reveal the gravel and cobble substrate for reproduction. Nests are built in low velocity areas because eggs and weak-swimming larvae will otherwise be swept away by even relatively slow water currents 5-22 cm/sec (Larimore and Duever 1968). Females are attracted to nests by males and eggs are deposited over the surface of the substrate. Fertilized eggs are marginally or not adhesive, and develop on the surface of substrate as the male guards them from predators. After hatching, larvae lie on the bottom for several days, and after 1-2 weeks rise from the substrate and gain buoyancy, while still being guarded by the male bass. Those vulnerable eggs and weak-swimming larvae are the life stages most susceptible to changes in flow rates that may sweep eggs and larvae away and reduce their survival, and so are the target of flow spikes. Our own observations from the Green River and Yampa River indicate that young smallmouth bass displaced from the nest by flow and turbidity events have very low survival (Bestgen and Hill 2016a). Water temperature reductions associated with the flow increases, caused by release of water from cooler strata of Flaming Gorge Reservoir, may also cause males to abandon nests, which is desirable because of increased predation on eggs and larvae by invertebrates and other fish. These life history traits make early life stages of smallmouth bass vulnerable to flow and water temperature disturbances.

Flow spike study component:

Determine Green River hydrologic year type

The decision to implement a flow spike should be dependent on hydrologic conditions in the Green River as well as the Yampa River (Figure 4). Years with substantial snowpack and prolonged and cool runoff may not require disturbance flows to reduce bass survival, because in those years, bass spawning is usually delayed. Conversely, years with average or lower snowpack may require a flow spike to reduce smallmouth bass reproductive success and induce a population-level impact. (See Green River Evaluation and Assessment Team [GREAT] report summary table). The reasoning behind choosing years with average and lower flow levels is that a Green River flow increase over base flow to 127.4 m^3/sec (4,500 ft^3/sec) will create a substantial change in stage over the duration of the flow spike and create flow-through side channels in many locations where bass spawn (KRB, unpublished observations). Another justification is that at higher flow levels, which are typically associated with cooler water temperatures, smallmouth bass reproduction is later in the year and bass may be small going into winter, which negatively affects their overwinter survival. Thus, a flow spike may not be needed in higher flow years, and will be less effective anyway, because of the lesser change in stage relative to a lower flow level. Information on flow year type will already have been assessed before spring flow recommendations are implemented and prior to the flow spike. Thus, no new information will need to be gathered on that aspect of hydrology.

Flow spike study component:

Determine Yampa River hydrology and study feasibility

A next step in the flow chart is to consider the hydrologic year conditions in the Yampa River. This is important mainly for the reach of the Green River downstream of the confluence of the Yampa River. For example, if flows are suitable in the regulated Green River reach (e.g., average or less), but very high in the Yampa River, a flow increase from Flaming Gorge Reservoir will be most effective in the regulated Green River reach but may be less effective in the partially regulated Green River reach. This is true because a maximum powerplant release at Flaming Gorge Dam will increase the flow stage and associated water velocities less in the partially regulated reach when Yampa River flows are high, compared to years when flows were lower. In such years, managers should still consider the benefit of conducting a flow spike to reduce reproduction by smallmouth bass in the regulated reach of the Green River upstream of the Yampa River. Additional information regarding flow levels needed to inundate side-channel habitat in the Green River downstream of the Yampa River where smallmouth bass spawn will guide future recommendations on the impact of Yampa River flows and whether to conduct a flow spike in higher flow years.

In an alternative scenario where Yampa River flows are substantially lower and warmer than Green River flows, other considerations arise. Smallmouth bass spawning may be delayed in the higher and cooler Green River, but lower Yampa River flows may promote earlier than normal spawning by Colorado pikeminnow and presence of larvae (Bestgen and Hill 2016b). This will trigger another FGTWG discussion of flow spike efficacy because a flow spike that occurs when Colorado pikeminnow larvae are drifting into the Green River from the lower Yampa River spawning area may negatively affect their survival, based on both increased flow magnitude and reduced water temperatures. Years when Green and Yampa River flows are predicted to be similar and at average or lower levels should promote good conditions for a flow spike, because smallmouth bass spawning should occur prior to spawning by pikeminnow.

Individual flow spike timing, magnitude, and duration.—To be most effective, timing of flow spikes to control smallmouth bass should be tailored to individual years and conditions (Table 1). Thus, a key piece of information needed to successfully reduce survival of early life stages of bass via disturbances (increase in flow and reduced water temperature) is predicting or observing the onset (timing) of bass reproduction. This information is crucial because a well-timed flow disturbance allows for maximum negative effects on a large portion of the annual smallmouth bass reproductive effort. Timing is also critical to minimize negative effects on native fishes and other resources. To facilitate predictions of reproduction timing, I have gathered several years of data that describe environmental conditions associated with onset of smallmouth bass spawning in the unregulated Yampa River, the regulated Green River upstream from the Yampa River, and the partially regulated Green River downstream from the Yampa River (Figure 2; Bestgen and Hill 2016a). In brief, I found that despite variable annual flow magnitude, hatching of smallmouth bass in the three sections of the Yampa and Green rivers is nearly always associated with increasing water temperatures during declining or stable baseflows, occurring soon after achieving a persistent mean daily water temperature threshold of about 16°C, with the date depending on the reach.

> **Flow spike study component**:
>
> Predict timing of smallmouth bass reproduction

Mean first hatching date for smallmouth bass in summer in the period 2004-2011 was 27 June in the regulated Green River reach and 23 June for the partially regulated Green River reach, with earlier spawning in all reaches in warm, lower flow years such as 2006 and 2007. Later spawning was noted in cooler, higher flow years such as 2011 (Figure 5; Bestgen and Hill 2016a, their Table 4). First spawning dates in those reaches were 7-11 days after water temperatures first achieved 16°C. Hatching duration for smallmouth bass in any given year averaged about 30 days after initiation, and peak hatching was usually within about two weeks after first hatching. Thus, in the first two weeks after first hatching, the majority of eggs annually deposited in spawning nests has occurred. Eggs deposited in the first week of the spawning season will also be hatched and larvae will begin swimming up. Because of presence of many vulnerable early life stage bass in those first two weeks of the hatching season, this would be an ideal time for a single annual flow spike to occur.

Once the decision to implement a flow spike is made and smallmouth bass reproduction timing has been estimated, the flow spike should begin. Flow spike magnitude should be increased to Flaming Gorge Dam power plant maximum flow levels of about 127.4 m^3/sec (4,500 ft^3/sec), with water drawn from the deepest and coolest portions of the reservoir possible. Several lines of evidence support using this flow magnitude for smallmouth bass suppression. First, habitat occupied by spawning smallmouth bass and their early life stages in the regulated and partially regulated reaches of the Green River occurs mainly in the downstream ends of cutoff side channels. Specific side channel backwaters or eddy locations include: just upstream of Hells Half Mile rapid (about RK 556.7, river right); just downstream of Wild Mountain campground (Screaming Jay backwater, about RK 562.4, river left); near the Green River confluence with the Yampa River (river left); as well as several sites in Whirlpool Canyon and the upstream end of Island Park. Preliminary flow and stage observations at selected backwaters in the Green River (those identified below as potential study sites) showed that maximum power plant flow level is needed to reconnect the main channel and side channels and achieve flow movement at a sufficient rate through those potential spawning areas. Flows to flush young smallmouth bass from stationary positions, based on laboratory studies, were achieved only when current velocities reached 5-22 cm/sec or higher in water temperatures of about 15-20°C (Larimore and Duever 1968), so those velocities seem the minimum needed to induce bass dispersal and potential mortality in the field. Data from 2011 also indicated that smallmouth bass did not spawn at flow levels of 127.4 m^3/sec (4,500 ft^3/sec) in spite of adequate water temperatures (Bestgen and Hill 2016a), indicating lack of spawning habitat. However, as soon as flows dropped to base levels (70.8 m^3/sec [2,500 ft^3/sec]) successful bass reproduction was nearly simultaneous, indicating habitat limitation at higher flow levels. Understanding various flow level effects requires assessing flow conditions in side channels during different levels of inundation and flows needed to achieve those velocities should be refined from powerplant level flows only after effects on young bass (displacement/mortality) are documented. In addition to flows required in the regulated reach of the Green River, power plant level releases are needed to effect a substantial change in flows and flow stage downstream in the partially regulated Green River reach.

Flow spike study component:

Release flow spike with magnitude at powerplant maximum, about 127.4 m^3/sec (4,500 ft^3/sec)

As an aside, some flow fluctuations already occur in the regulated Green River reach, and to a lesser extent, the partially regulated reach, due to daily flow fluctuations from hydropower production. For example, daily flow fluctuations at Flaming Gorge Dam in September 2017 range from about 42.5 m^3/sec to just over 73.6 m^3/sec (1,500 to just over 2,600 ft^3/sec). Those fluctuations result in stage changes just downstream of the dam of about 30 cm, based on measurements at the US Geological Survey gauging station. However, by the time those flows reach Lodore Canyon, the first reach where smallmouth bass occur and may be negatively affected, flow stage changes have attenuated and are often 15 cm or less, based on diel observations. Observations show those changes are insufficient to cause substantial or any changes in the relative degree of connections of side channels with the main channel. It is also likely that smallmouth bass, in a fluctuating flow environment, will choose locations for nesting based on lowest flow levels, such that nests are built in areas that have suitable characteristics in spite of modest stage changes in that range. Hence, higher flow and stage changes and more sustained flows are needed to effect negative changes in bass reproductive success than those observed during normal base flow periods. I know this because smallmouth bass have successfully reproduced in the Lodore Canyon reach of the Green River every year since their initial invasion in 2003. Again, a good illustration of the need for this flow level is from 2011 Green River Lodore Canyon data (Bestgen and Hill 2016a), where at flows of 127.4 m^3/sec (4,500 ft^3/sec), no successful bass spawning was observed, in spite of adequate water temperatures. After flows dropped to 70.8 m^3/sec (2,500 ft^3/sec), successful spawning was observed within 3 days.

Although a lesser flow than powerplant capacity could be considered, such as in the Yampa River in summer 2015 when a thunderstorm produced a flow spike, that is not recommended at this time. One reason is that even though the spike magnitude was relatively low (36.8 m^3/sec [1,300 ft^3/sec]), the flood event more than doubled Yampa River flow from about 31.1 m^3/sec (1,100 ft^3/sec) on 7 July to > 68 m^3/sec (2,400 ft^3/sec) on 9 July. The Yampa River flow spike was of lesser magnitude, but I argue that differences in the environmental setting and flood characteristics do not make the Yampa and Green rivers comparable, and that simply because a flood of a certain magnitude in one stream was effective does not mean it will be effective in another. For example, the Yampa River flood had a significant amount of turbidity associated with increased flow magnitude, which has a known negative effect on early life stages of smallmouth bass (Winemiller and Taylor 1982). Because clear flows will be released from Flaming Gorge Dam, I expect there will be only a negligible increase in turbidity in the Green River, so the main flow effect needs to be a large one to ensure a substantial negative effect on bass. Flow levels > 127.4 m^3/sec (4,500 ft^3/sec) were considered but not proposed because those may create challenges that limit use of bypass tubes only for other purposes, use of which is required to produce higher flow levels. The stage change associated with that flow increase was about 37 cm, based on the stage-discharge relationship for that site (U. S. Geological Survey, Maybell gauge, 09251000). Thus, a large area of bass-occupied habitat was inundated with greater flows and velocities in the Yampa River, an effect which should be duplicated in the Green River. It is possible that after some of the first studies are conducted, data will be available to support a lower flow release in some circumstances. However, these first flow spike studies should be designed to have maximal effect so that some positive benefit is as likely as possible, especially given the extensive coordination and logistics efforts that this evaluation will require, as well as the declining status of Colorado pikeminnow.

Flow spike study component:

Releases the coldest water possible

Reservoir water released to produce flow spikes at powerplant capacity (e.g., 127.4 m^3/sec [4,500 ft^3/sec]) should be as cold as possible. This will require dropping the selective withdrawal structure (SWS) gates as deep as possible because surface temperatures will be warmer. Normally, SWS gates are expected to be near the warmer surface water by mid-June (about 12 m). Reducing gate elevation during a flow spike will draw from cooler reservoir levels and should lower release temperatures depending on the levels of reservoir stratification by up to 5°C (from 11 to 5°C). This is supported by June water temperature profiles from the forebay of Flaming Gorge Reservoir (unpublished information, Green River flow and water temperature evaluation). High flows and relatively fast downstream travel times will preserve those cooler water temperatures relatively far downstream, likely to and through Lodore Canyon. Effects of cold release water temperatures and fast downstream travel times on water temperatures at Lodore Canyon are in annual reports for Project FR115 (http://www.coloradoriverrecovery.org/documents-publications/work-plan-documents/project-annual-reports.html, e.g., Figure 1, 2018 annual report and Muth et al. 2000; Bestgen and Crist 2000, U. S. Bureau of Reclamation Flaming Gorge Operations annual reports). How far cold water temperatures are preserved downstream in the Green River depends on the release volume, temperature of releases relative to atmospheric temperature, magnitude of daytime warming, rates of travel, and downstream of Echo Park, the volume and temperature of the Yampa River. Maintaining cooler water downstream during a flow spike is important because shifts to cooler water temperatures are also known to contribute to nest abandonment by guarding male smallmouth bass and reductions in survival of young.

At this time, I consider the flow spike effects and water temperature reductions to be a single treatment, with both effects intended to reduce reproductive success. Data gathered will assist with deciphering whether only high flows are needed or if high flows and reduced water temperatures are most effective. It may be evident if only flow, or if flow and temperature are both needed, but only after two or more flow spike study years. Evaluation of inundation of smallmouth bass spawning habitat, observations of water temperature change as flows proceed downstream, and analysis of sampling data to assess effects on bass will be useful to make those assessments. Water temperature reduction as a management option without a flow spike is not considered a viable option at this time, but can be evaluated after initial experiments are completed. Prospects for only a temperature reduction experiment to work are considered relatively low because slower flowing water will warm quickly and have a relatively small effect on bass-occupied habitat.

Flow spike study component:

Release water for 3-day period

Flow duration to produce maximum negative effects on smallmouth bass reproduction is not precisely known, but three days should be adequate to ensure most bass early life stages are exposed to higher flows. This is because water travel time at 127.4 m^3/sec (4,500 ft^3/sec) from Flaming Gorge Dam to the downstream end of the study area, at least lower Rainbow Park, is substantial at about 30 hr, when Yampa flows are low at about 28.3 m^3/sec (1,000 ft^3/sec). The 3-day release period will then be sufficient to create flow-through connections in the desired habitat areas for at least two full days, given flood wave attenuation effects as flows rise and fall downstream during and after releases, respectively. The 3-day release will also allow investigators to traverse the mostly canyon-bound and relatively long reach in inflatable rafts to assess effects of the flow disturbance on habitat and biota at various locations.

Flow spike study component:

End release, continue to monitor resources

After the 3-day flow release, flows should be dropped as fast as possible. Monitoring of fish response and other resources such channel morphology and nonnative vegetation should continue. Ending the release quickly will conserve water and alleviate concerns that flow elevation may enhance survival of nonnative shrub seedlings, if any are present (Friedman 2018). In most or all years, flow spikes will occur prior to presence of seed rain from local or upstream stands of nonnative shrubs, based on Cooper et al. (1999; Figure 6). Thus, I do not anticipate that flow spikes will enhance survival of seedlings because they should not be present. If a few seedlings are present, increased flow magnitude should float shallowly rooted seedlings from the substrate, or conversely, strand them in a zone too dry for their survival after the flow spike recedes from maximum level. Regardless, the flow spike should not benefit nonnative shrubs in the Green River study area. Nevertheless, a plan is under development to monitor nonnative woody shrub distribution and abundance and channel change in the Green River, in relation to flow spike and elevated base flow management.

Flow spike evaluation

After a time and conditions for a flow spike event are established, a monitoring strategy must be in place to measure flow spike effects on habitat, smallmouth bass and other native fishes, and other resources (Table 2). Physical habitat changes associated with flow increases in smallmouth bass habitat should focus on those characteristics that may be altered (increased velocity over the nest, reconnection of a side channel) given a certain flow increase. I have several sentinel sites already chosen that include mainly side channel backwaters, including the ones mentioned above. At each location, study teams will measure connections, flow velocities, water temperatures, and water turbidity in pre-release, during-release, and post-release periods to assess levels of connections with side channels and the main channel. Water temperatures may also be monitored at specific sites using water temperature loggers, to supplement those that are placed in various locations (six in all including USGS gages) from the dam downstream to near Jensen, Utah.

Associated with those site visits are biological measurements. Backwater, side channel, and nearshore seine sampling is conducted in the Green River in regulated and partially regulated reaches in summer and autumn as a part of Recovery Program Project FR-115 (Bestgen et al. 2006). A sampling pass will be added to that protocol just before the flow spike to document native and nonnative fish densities, including those for smallmouth bass. Seining conducted will permit calculation of density estimates of fish, including bass, based on area swept by the seine, before the flow spike occurs. Ideally, understanding effects of flow spikes involves finding and marking nests, and taking measurements of the velocity and depth characteristics around the nest area, and describing macro-habitat features of the site, including where the nest was located in the secondary channel. Field crews have had some success at finding nests at those locations in the past and expect at least a few will be monitored. Observations may also include finding and marking locations of newly dispersed smallmouth bass larvae that occupy low velocity areas that are typically very near channel margins. In the regulated Green River reach upstream of Lodore Canyon, field surveys revealed several locations where smallmouth bass have spawned in the past, based on capture of adults guarding nests, presence of larvae, or both.

Density of resident fishes including smallmouth bass will then be estimated with seine sampling in backwaters in summer and autumn after flow disturbance occurs. Data gathered will allow comparison of pre and post-flow spike densities on a larger, river scale, both within that year, and through time using comparisons with historical data. Density of young bass will also be assessed in autumn, and compared to previous years when no flow disturbance events occurred. Similar to smallmouth bass, densities of native fishes captured in autumn after flow disturbances (Project FR115; Bestgen et al. 2006; 2007b; 2007c) will be compared to those in previous years to assess if there were effects from flow disturbances, understanding that these abundances vary due to many factors.

Field sampling may also estimate occupancy of young smallmouth bass in and around low velocity areas pre- and post-disturbance, if sufficient sample sizes needed for meaningful analyses can be gathered. This approach entails taking a minimum of two samples at each site, say a suspected nest area or an adjacent channel margin (Figure 7). Occupancy estimation approaches allow estimation and correction of the likelihood that a species went undetected but was actually present (false absence). Occupancy estimation conducted before and after disturbance will allow comparisons of effects of the disturbance on presence of smallmouth bass young in low velocity habitats, with the hypothesis that occupancy will be reduced post flow spike. Some simulation modeling needs to be conducted to determine if this is a viable approach, given the likely number of samples that can be collected.

Drift nets are effective to capture early life stages of smallmouth bass during flow disruption events. For example, early life stages of smallmouth bass were captured in the Green River just upstream of the Yampa River during higher flow and turbidity conditions caused by upstream rain events in 2003 and 2004 (Bestgen et al. 2006). Thus, bass larvae were dispersed and were captured in drift nets. Drift net sampling during flow spike events would be useful, where timing of sampling will coincide with the rising and maximum portion of the flow spike, to ensure that bass detection opportunities are maximized.

Although the previously mentioned measurements and observations will be informative especially for documenting the mechanism of a flow spike effect, otolith analysis of smallmouth bass captured in summer and autumn may best demonstrate effectiveness of flow spikes to reduce survival of larvae. This technique was effectively used in the Yampa River as well as the partially regulated reach of the Green River after the summer 2015 flood (Figure 8). Samples of bass captured in autumn will be aged via otolith microstructure to determine if any smallmouth bass survived from the time period prior to the flow spike(s). This will be similar to constructing the hatch date distributions already shown here and in Bestgen and Hill (2016a). A main difference is knowing that bass actually spawned based on observations and sampling conducted pre-disturbance, or if that was not possible, based on temperature-spawning relationships. In other words, if all bass captured in autumn were produced post-disturbance, and bass were known to be spawned in a pre-disturbance time period but few or none were captured in autumn, the disturbance should be assumed effective. Those same otolith-based assessments will be made in the partially regulated reach of the Green River. Locations of bass nesting are known, including the lower ends of cutoff, low flow channels, or large backwaters in Whirlpool Canyon and Island Park. A key to success again is flows that are large enough to connect side channels and disrupt nests and displace larvae.

Yet another source of data to evaluate effects of flow spikes on smallmouth bass reproductive success is sampling conducted during bass removal in the Green River from Echo Park to Split Mountain boat ramp (Project 123a annual reports, http://www.coloradoriverrecovery.org/documents-publications/technical-reports/technical-reports.html). That project removes smallmouth bass in various size categories and reports catch/effort statistics and abundance estimates (prior to 2011, and after 2015). Changes in abundance and catch rate data collected in years when no flow spike treatment is attempted will be compared to those years when the flow spike treatment is implemented. Perhaps more useful is the length-frequency data collected from captured smallmouth bass, which can show changes in abundance of young age classes in prior years. For example, data reported in 2016 for early summer sampling passes showed a dearth of age-1 (produced in 2015) smallmouth bass in the reach (Figure 9; from 2016 annual project report 123a, http://www.coloradoriverrecovery.org/documents-publications/technical-reports/technical-reports.html, Jones et al. 2016). The likely cause for absence of those sizes of fish, compared to other years when they were abundant, is the flow and turbidity spike from the Yampa River and the downstream Green River in mid-July 2015, with much reduced reproduction in the reach.

Future considerations for flow management to disadvantage smallmouth bass, Green River

The prior discussion details a standard approach to implement a flow spike to reduce smallmouth bass spawning success in the Green River downstream of Flaming Gorge Dam. This section describes some additional considerations that may alter the study plan in the future. Alterations to the study plan should occur only after some initial data are available (2 years or more) to guide such changes.

Intra-year flow spike frequency.—Our initial efforts to use flow spikes to suppress smallmouth bass will focus on use of a single flow spike per year. A single flow spike is likely suitable because hatching seasons spanned relatively short time periods, and modeling indicated that infrequent but well-timed disturbances may have a substantial negative impact on survival of bass early life stages. If flow spikes are less effective than hypothesized, or if later portions of the hatching period produce large numbers of bass larvae that are unaffected by the flow spike, use of additional flow spikes should be considered. Efforts to suppress reproduction and abundance of age-0 bass should focus on cohorts hatching early in the year because those fish are the largest ones in autumn and the most likely to survive the winter in the Yampa and Green rivers, assertions supported by smallmouth bass population dynamics modeling (Breton et al. 2015). Timing of reproduction and growth information should assist with understanding population dynamics of smallmouth bass in large western rivers including the Yampa and Green, and inform actions that may reduce their abundance and impacts on native fauna.

Other flow-related management programs and factors.—The proposed flow spike is positioned in the middle of the period when other flow release actions at Flaming Gorge Dam, including early spring flows to provide floodplain wetland habitat for young razorback suckers and later, base flows in summer to enhance survival of Colorado pikeminnow young. Thus, flow spikes to disadvantage smallmouth bass will overlap minimally or not at all with other flow management efforts, even if all were implemented in a single year. However, vagaries in flow and water temperature regimes, which may alter timing of Colorado pikeminnow reproduction in the Yampa River, need to be factored into a decision to implement a flow spike for smallmouth bass suppression in the adjacent Green River.

In years when the hydrology of the Yampa and Green rivers is similar, overlap of spawning seasons for bass and pikeminnow are not anticipated. This is because mean first presence date for Colorado pikeminnow larvae in the Yampa River is about 5 July, or 8-10 d after mean first smallmouth bass hatching (e.g., Figure 3). However, because few pikeminnow typically occur in the early portion of the spawning season, overlap should be minimal for 10-14 d after smallmouth bass first hatch. This is important because high flows during a flow spike may negatively affect survival of Colorado pikeminnow larvae as they are transported downstream from the Yampa River into the Green River. The overlap period merits careful attention however, particularly if climatic and flow conditions differ greatly between the Yampa River and upper Green River basins. For example, if flows in the Yampa River are especially low and warm compared to higher releases from Flaming Gorge Dam, earlier pikeminnow spawning and greater overlap with the Green River bass spawning season will be expected, and the potential for negative flow spike effects on pikeminnow larvae may be an issue. This will merit further discussion by the FGTWG. Alternatively, if flows were lower and relatively warm in the Green River, and were higher and cooler in the Yampa River, less overlap will be expected because bass will spawn earlier and pikeminnow later. The largest peak of the Colorado pikeminnow drift period is typically 2-3 weeks after larvae first appear, and usually in the third week of July. In the example shown (Figure 10), first 2007 Colorado pikeminnow drift into the Green River was on 26 June and the first substantial pulse of larvae was on 7 July. Thus, the end of the smallmouth bass hatching period typically barely overlapped with that of the first larger pulse of Colorado pikeminnow larvae of the year, so earlier flow spikes should not affect pikeminnow drift patterns.

Targeting the early portion of the smallmouth bass hatching period will also reduce the chance that flow disruptions will affect spawning and drift of other native fishes. This is true because such a flow disturbance will occur after reproduction by most native suckers, but just prior to spawning by chubs and Colorado pikeminnow in the Green and Yampa rivers. Flow disturbances will likely also affect native fish eggs less than smallmouth bass eggs. This is true because smallmouth bass lay eggs, which are only marginally adhesive, on the top of substrates in nests constructed in low velocity habitat, which will likely be swept away with relatively small increases in flow velocity near the benthos. In contrast, native fish reproduction occurs in high velocity runs and riffles, where adhesive eggs are deposited in deeper interstitial spaces of substrate and attach to large cobble and gravel particles. Thus, eggs are attached and placed below the surface of the substrate and will be less affected by flow increases in habitat that is already flowing relatively swiftly.

Specifics of timing of releases for disruption of reproduction should be further refined using smallmouth bass hatching date distributions and predicted smallmouth bass spawning times (Bestgen and Hill 2016a), and verified with observations when possible. Certainly, disturbance flows will be post-spawning and post-hatching, but whether to target cohort 1 (early cohort) or 2 (middle cohort), or both, is not certain (Figure 5); flows may target both simultaneously, given the short time between initiation of hatching and the peak in the distributions of hatching dates. Targeting the peak time of hatching will follow production of Cohort 1 fish, typically the largest fish produced in any year, and also the first portion of Cohort 2, which is typically the one with most bass produced in any year.

Other flow management considerations.—It may be also worth discussing the option of lowering post-peak-runoff early summer releases from Flaming Gorge Dam to low and steady baseflow levels, which will naturally warm water temperatures and induce smallmouth bass reproduction early in the post-peak period. This is potentially important because baseflow levels established early to induce smallmouth bass reproduction in warm and stable flow levels could be used in concert with subsequent flow spikes or colder water temperatures (or both) to more effectively disrupt spawning or hatching. Subsequent flows will have a larger effect in terms of increased stage as well as in reduced water temperatures, and may create more certainty that most smallmouth bass will be attempting to spawn in the reach of interest when the disturbance is attempted. This scheme will also induce spawning earlier than might normally occur, so that the flow spike does not overlap with onset of Colorado pikeminnow larvae drift into the Green River. It may be that much reduced early flows should be considered only after the efficacy of the technique of flow spikes to reduce smallmouth bass reproductive success has been demonstrated.

Reducing flows early in the season in the regulated reach of the Green River may have additional benefits for non-native fish control (Zelasko et al. 2015). That is because northern pike *Esox lucius*, which spawn during high flow releases in the Browns Park area of the upper Green River, may be negatively impacted by early season flow reductions because of reduced survival of young. High abundance of young northern pike observed in both recent high and extended flow years in Browns Park (2011, 2017) indicates that pike respond positively to higher flows if they occur over extended periods. This may be because northern pike are attracted to spawn in areas of shallow submerged vegetation in the flood plain or the channel margin during higher flows in May and early June. If flows are reduced when sensitive eggs or larvae are present in the shallow floodplain or the channel margin, those life stages may be stranded or flushed to the river, resulting in lower survival.

Study duration for smallmouth bass flow spikes, in terms of number of years to conduct this investigation is not known, and is largely dependent on the relative success of flow disturbances to reduce smallmouth bass abundance. However, a minimum of five successful flow spike releases and evaluations should be conducted after which a longer-term evaluation will be conducted. This study duration seems the minimum needed to test a range of flow scenarios (moderate to low hydrology years) that will likely occur. Study years need not be consecutive given that flow levels may not be conducive to success in high flow years, and in certain year's flow spikes may prove difficult to implement alongside other flow experiments such as LTSP or altered summer baseflows. Annual evaluations in the form of data comparisons and summaries will be presented in Recovery Program annual reports.

Uncertainties.—Smallmouth bass are known to renest following disturbances that destroy nests in lentic systems (Winemiller and Taylor 1982), but it is not known if this will occur in lotic habitat in the upper Green River system. Even if renesting occurred, the relatively late hatching fish that remained may experience lower overwinter survival because of small body size during winter (Shuter et al. 1980, Breton et al. 2015). In other words, the short time window for reproduction in this system, combined with the removal of early cohorts, may be effective enough to create a large and negative effect on smallmouth bass recruitment.

An important consideration for implementing flow management actions is to identify if sufficient water is available to conduct fish management releases in a single flow year, and if not, which action(s) have the highest priority for implementation. A key part of that determination is the hydrologic conditions present in the upper Green River basin in a given flow year. For example, extensive floodplain inundation is achievable and important, but more difficult, in low magnitude flow years. Conversely, smallmouth bass flow disruptions may work best in low flow years, given that such years are the ones best suited for bass recruitment and because those flow management events are short-term and relatively low volume releases. The duration and magnitude of various flow prescriptions, the amount of water available in Flaming Gorge Reservoir, reservoir inflow forecasts, drought and storage trends, status or abundance on non-native fish, and the many other competing uses for that water need to be considered as well. An advantage in this system is that Flaming Gorge Reservoir has a relatively large storage volume, and the amount of flow required may be modest relative to the overall storage capacity and inflows into the system. In fact, flow modeling has shown that smallmouth bass flow spikes have a nearly negligible effect on reservoir volumes and are not a significant impediment to the conduct of other flow management activities (personal communication, H. Patno, hydrologist, U.S. Bureau of Reclamation, Salt Lake City, Utah). Adaptation of this flow spike plan to other locations in the upper Colorado River basin is presented in Appendix I.

Another uncertainty is the effects of the increased short-term flow on other resources such as nonnative vegetation (Friedman 2018). Concerns are based on the idea that elevated flows may enhance nonnative shrubby vegetation and eventually reduce Green River channel width and complexity. A plan is being developed to monitor vegetation responses and channel changes over time so flow management effects can be assessed.

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Table 1. Characteristics and conditions for a single (1) Green River flow spike annually to disadvantage smallmouth bass (SMB) reproduction in the Green River downstream of Flaming Gorge Dam, Colorado and Utah.

Aspect of Flow Spike	Expected Range	Determining Factors
Timing	Mid-June – late July	• Type of flow year (earlier implementation in years with lower flows and warmer temperatures) • Predicted and observed SMB spawning and hatching dates • SMB hatch cohort to be targeted
Magnitude of release	127.4 m^3/sec (4500 ft^3/sec)	• Release should be sufficient to connect side channels with the main channel and achieve sufficient flow velocity through potential spawning and nursery areas • Yampa River flows and changes in flow may affect magnitude of the required FG release • Desired magnitude of releases may be refined following observations of effects on young SMB displacement/mortality
Duration of release	3 or more days	• Sufficient to create SMB nest disturbance and inhibit immediate adult re-nesting • Sufficient time for field crews to assess the impact of flow disturbance on habitat and biota at various locations
Downramping of release rate	As rapidly as possible	• Faster downramp rates conserve water and likely reduce opportunities for nonnative vegetation to become established in wetted unvegetated areas
Frequency of implementation	Up to 70% of years	• Water available to conduct flow spike release, and priority of a spike relative to other releases for fish management • Likelihood that proposed release can effect enough of a change in the physical habitat to reduce spawning success • The 30% wettest years are unlikely to present favorable conditions for a flow spike • Years in which the Yampa and Green River hydrologies differ greatly may be better or worse conditions for success
Feasible lead time	10-14 days	• Accuracy and reliability of SMB hatching models • SMB field observations • Release scheduling announcements
Number of years implemented	Minimum of 5 years with flow spike releases and evaluations; depending on results, more may be needed	• Success of the flow disturbances in reducing young and adult SMB abundance, each which has different time horizons • Positive (not negative) responses detected in native fish

Table 2. Proposed monitoring activities for Green River flow spike studies to disadvantage smallmouth bass (SMB) reproduction in the Green River downstream of Flaming Gorge Dam, Colorado and Utah.

PARAMETERS	FIELD ACTIVITIES	PURPOSES
Physical Habitat Changes:		
Flow velocity over SMB nests **Side channel reconnections** **Turbidity** **Temperature**	• Find and mark SMB nests • Measure pre-release, during-release, and post-release water velocity, turbidity, and depth at nests • Describe microhabitat features at each nest site, including location in the secondary channel • Monitor temperatures in main channel and side channels before and during flow spike at various locations across the study reach	• Determine effects of flow spikes on physical habitat characteristics • Determine flow levels needed to connect side channels providing observed or potential spawning habitat for SMB • Measure water temperature decline during flow releases which may disrupt bass spawning
Biological Measurements:		
Presence & abundance of larvae of all species **Estimated occupancy of SMB in and around low-velocity areas pre-and post-disturbance** **Density of young SMB**	• Find and mark SMB nests • Perform observations pre-flow disturbance or seine sampling post-flow disturbance at specific sentinel sites • Find locations of SMB larvae and compare with pre-flow spike locations • Drift net sample to capture early life stages of SMB during rising & maximum portion of the flow spike hydrograph and verify dispersion • Assess densities of SMB age classes in autumn, and compare to previous years • Perform otolith analyses of SMB captured in summer and autumn	• Assess whether increased flow removed SMB from nests or dispersed early life stages from the site • Determine flow levels needed to disperse early life stages of SMB • Assess effectiveness of flow spikes in reducing survival of SMB larvae
Changes in abundance of young SMB age classes from prior years	• Evaluate SMB catch/effort statistics for Green River from Echo Park to Split Mountain Boat Launch (Project 123a)	• Infer the role of flow spikes and other factors in prior years on SMB reproduction and survival

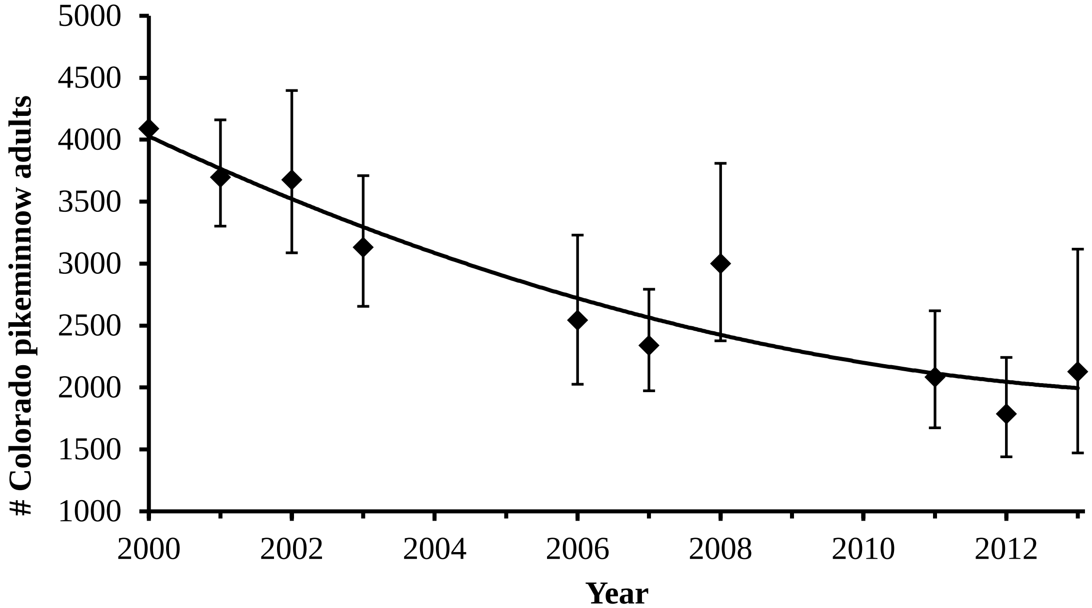

Figure 1. Abundance trend for adult Colorado pikeminnow in the Green River basin, including the mainstem Green River, and warmwater portions of the White and Yampa rivers, showing decline over time. Abundance estimates are based on capture-recapture sampling in five reaches; error bars are 95% confidence intervals (from Bestgen et al. 2018).

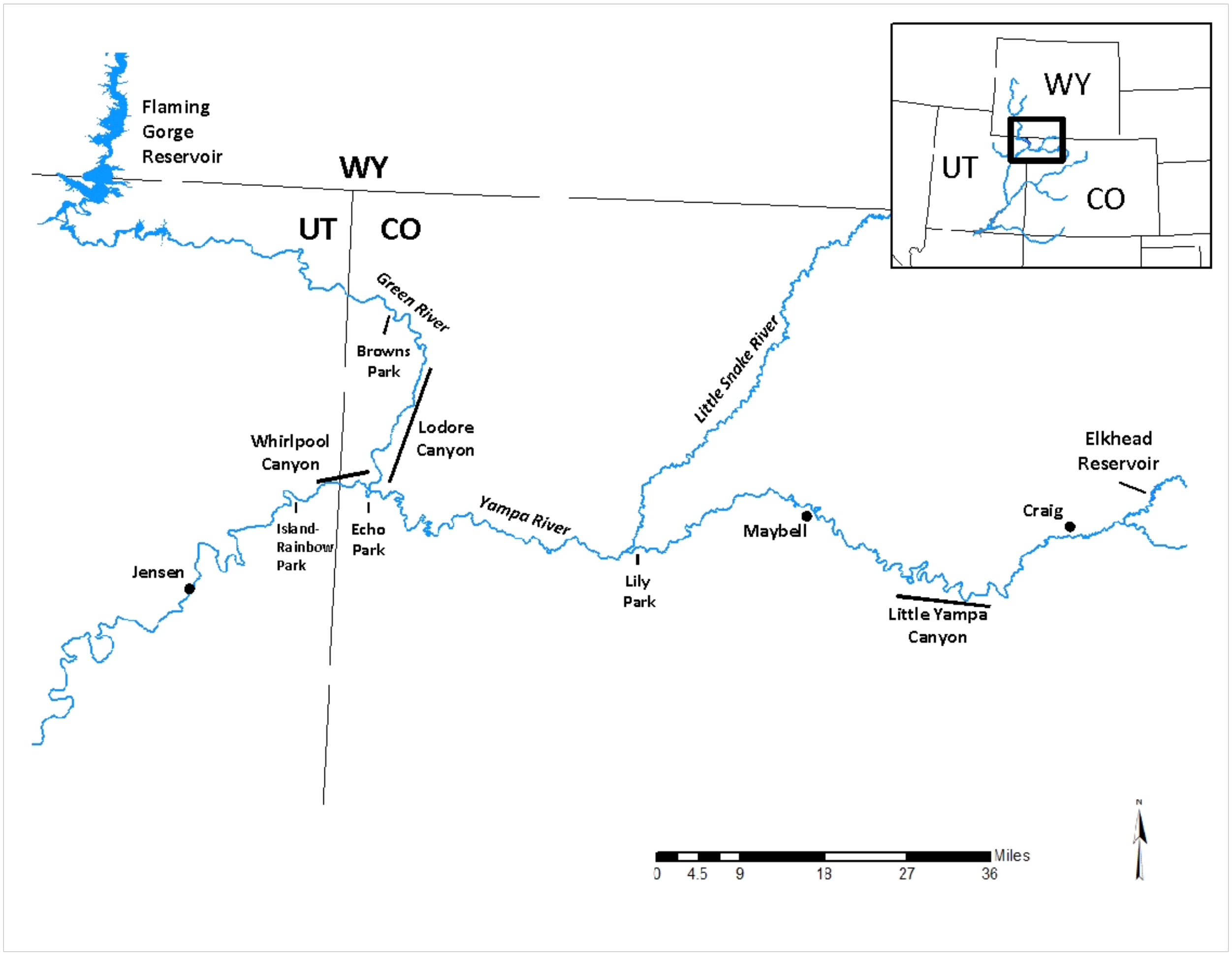

Figure 2. The Yampa River subbasin and the upper Green River basin including the Yampa River-Green River confluence at Echo Park in Dinosaur National Monument. Main study areas are Lodore Canyon and Whirlpool Canyon in the Green River and Little Yampa Canyon in the Yampa River.

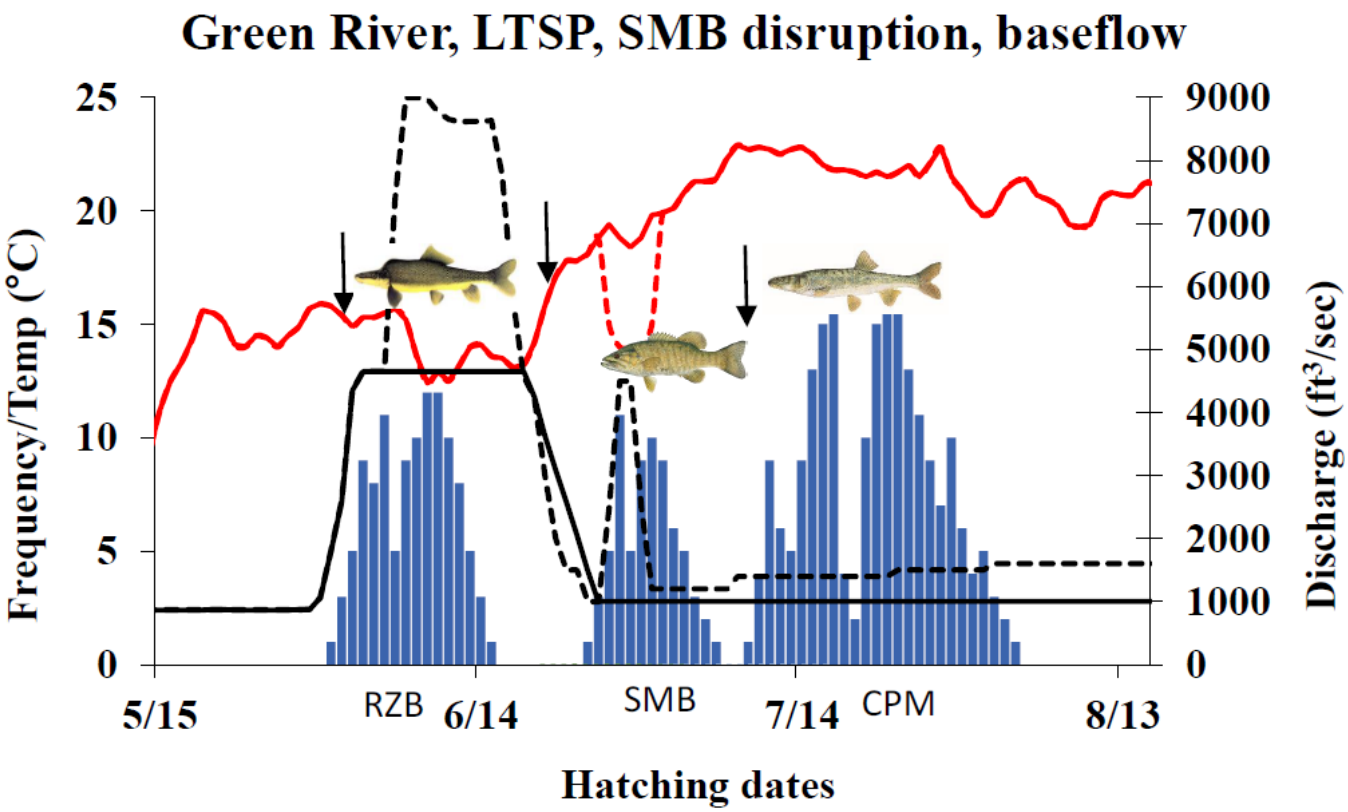

Figure 3. Conceptual diagram showing temporal sequencing of flow and water temperature regimes to benefit native razorback sucker (RZB) and Colorado pikeminnow (CPM) and disadvantage invasive smallmouth bass (SMB) in the Green River, downstream of Flaming Gorge Dam. Hatching dates for each species (indicated by arrows) are well-known and used to trigger flow management actions at appropriate times. Solid black line indicates a standard flow release from Flaming Gorge Dam under the 2006 Record of Decision. The dashed line indicates proposed (and presently implemented) higher magnitude flows for razorback sucker in spring under the Larval Trigger Study Plan to promote floodplain connection with the Green River, the flow spike in late June designed to disadvantage the early portion of smallmouth bass reproduction, and increased baseflows in summer designed to benefit age-0 Colorado pikeminnow in Green River nursery backwaters. The water temperature decline associated with the late June flow during smallmouth bass hatching could be effected either by reduced water warming as higher flows proceed downstream more quickly, or by releasing colder water from the variable elevation penstocks at Flaming Gorge Dam.

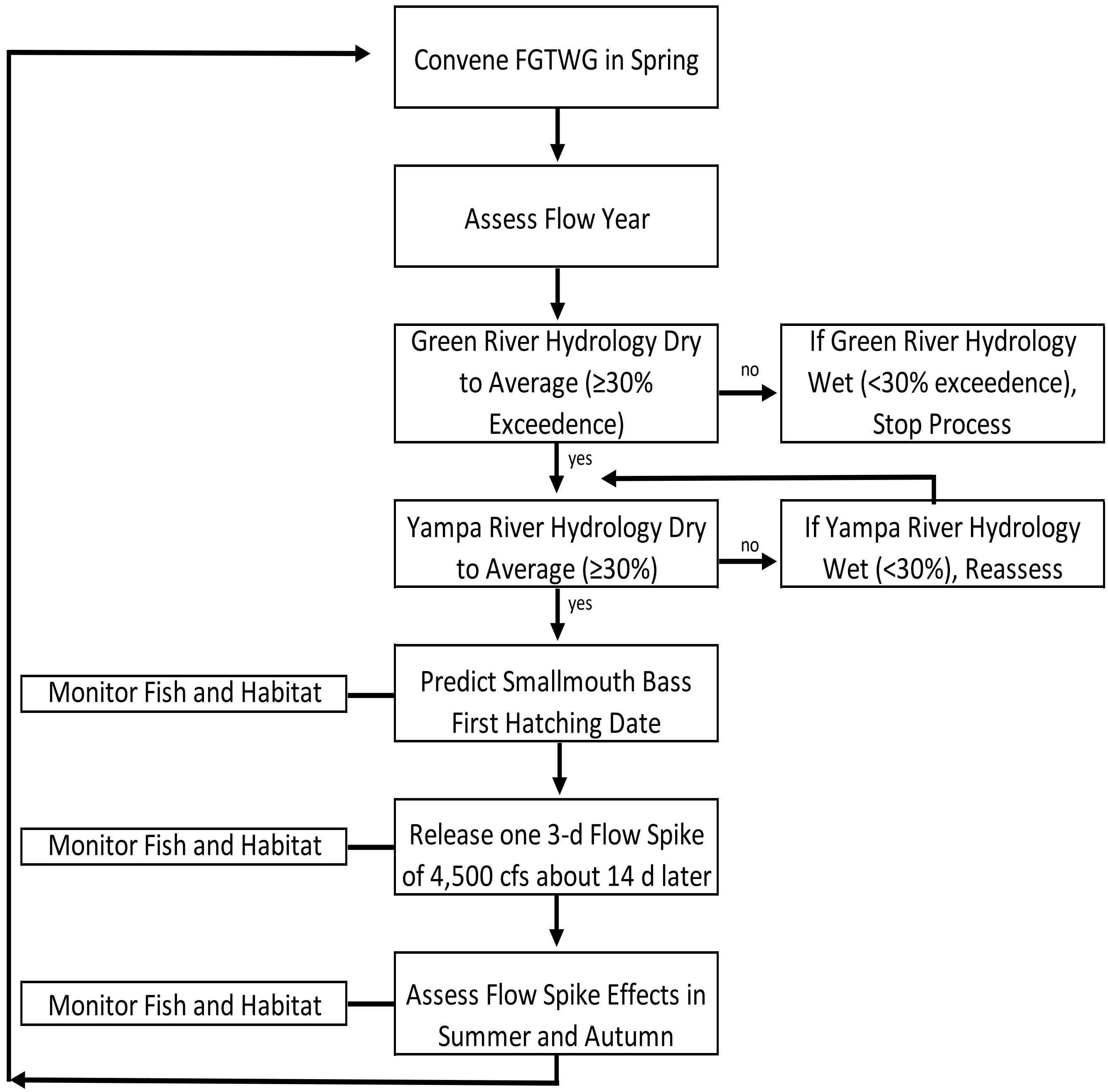

Figure 4. Flow chart describing the annual process to determine if a flow spike should occur from Flaming Gorge Dam and the schedule of events during and following such a disturbance.

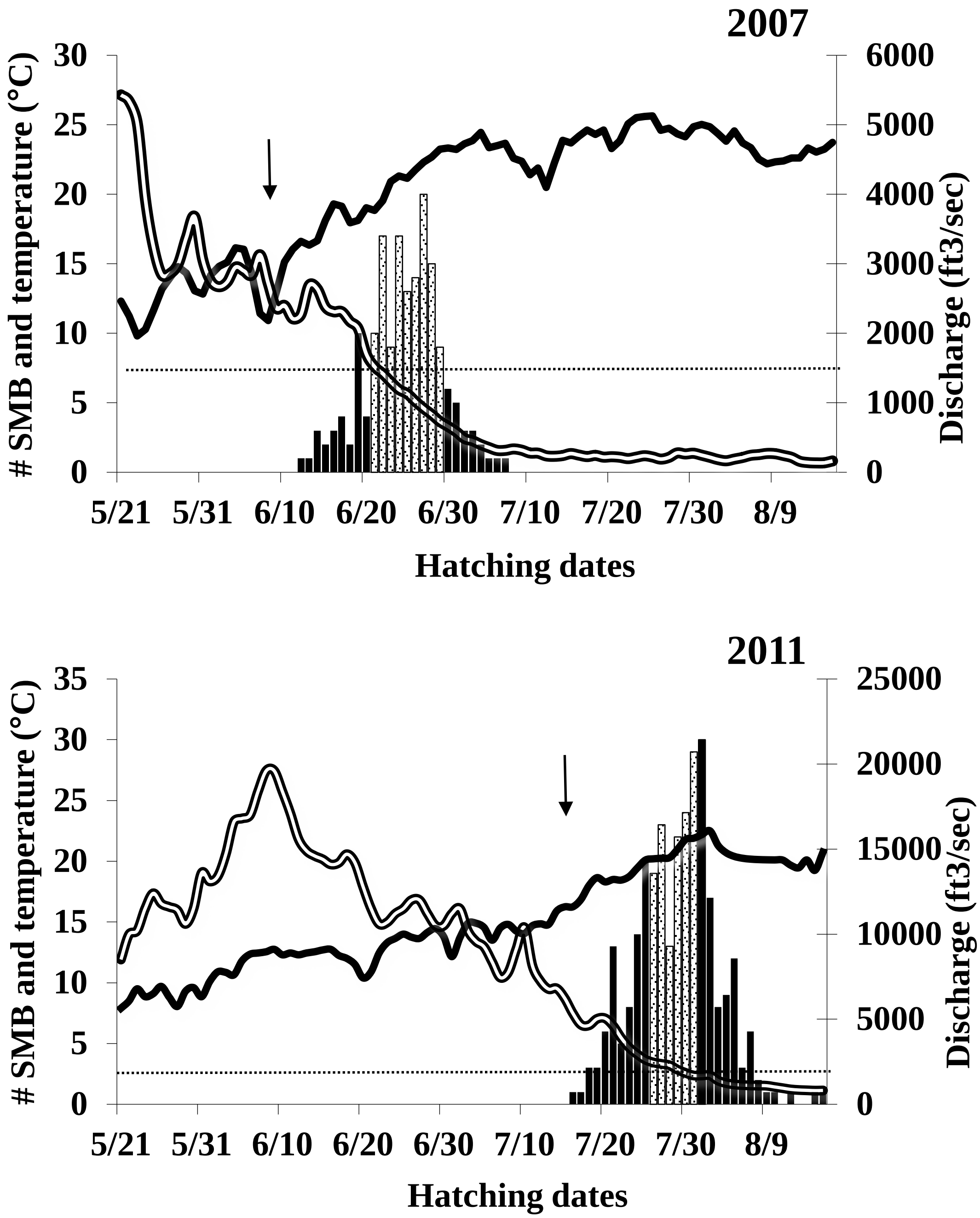

Figure 5. Distributions of hatching dates and smallmouth bass (SMB) abundance in samples collected in the Yampa River (bars), showing effects of a low flow (discharge is declining trace with the double line, water temperature the increasing solid line, through summer) in warm year (2007) compared to a higher flow and cooler year (2011). The vertical arrow indicates onset of mean daily water temperatures > 16°C. Hatching dates are divided into early (left filled bars), middle (shaded), and late cohorts (right filled bars).

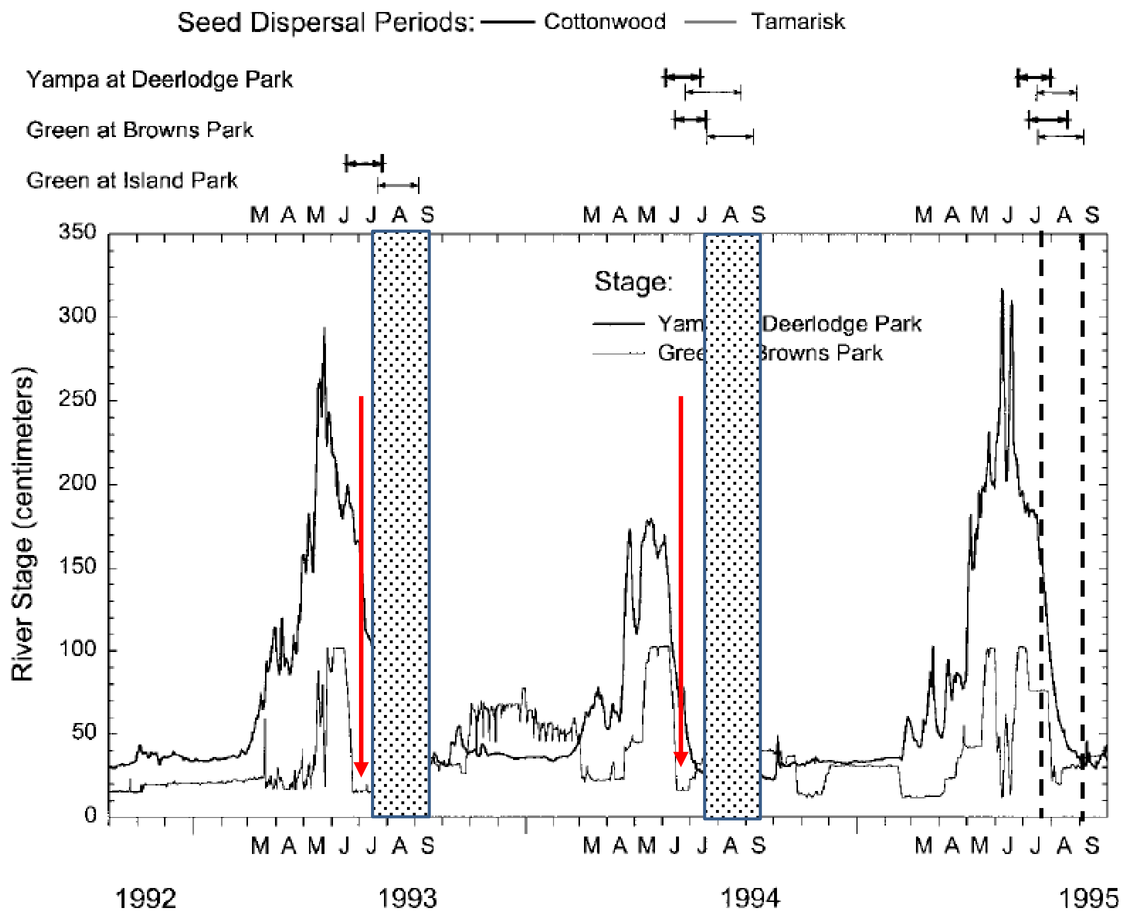

Figure 6. Modified figure of timing of tamarisk seed rain (Grey, stippled boxes, extended from arrow over graph, adapted from Cooper et al. 1993) in the Green River study area to show timing of smallmouth bass flow spikes (red arrows). Flow spikes will occur before tamarisk seeds are available for germination, according to these data, so flow spikes should not promote nonnative vegetation. Timing of flow spike not shown in 1995 because that was a relatively high flow year when no flow spike would be implemented.

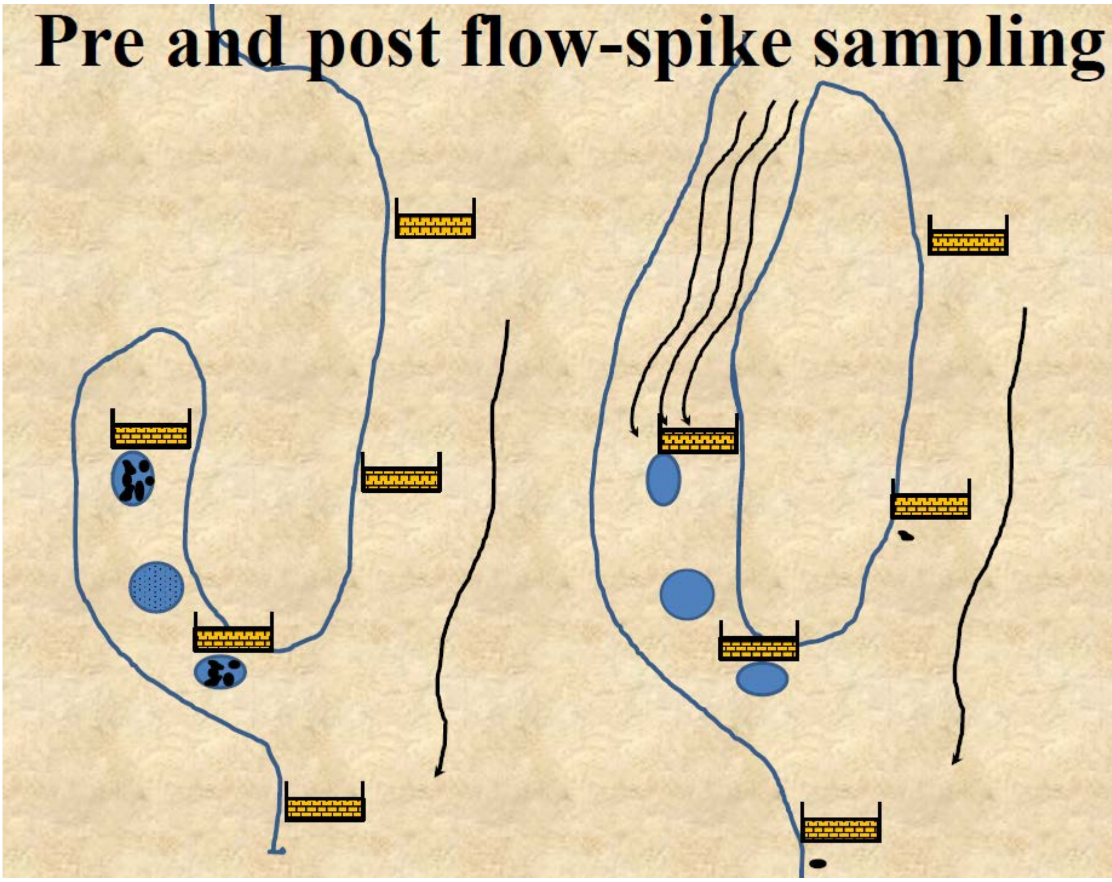

Figure 7. Hypothetical pre- (left figure) and post (right figure) flow spike sampling in and around a channel margin backwater. River flow in this figure is from top to bottom. Orange symbols denote sampling locations; blue ovals indicate bass spawning nests with or without young bass or eggs (smaller black dots). This scenario depicts a side channel backwater before and after it connects with the main stem during a flow spike, with the post-spike bass removed from nests, dispersed elsewhere, and much reduced in abundance. Samples taken in the backwater will document pre-disturbance occupancy by bass and also presence in other nearby localities. Post-disturbance sampling will document changes in density or presence, as well as potential dispersion of young bass to other nearby locations. Occupancy estimation sampling approaches could be used to estimate likelihood of false absences of bass in samples.

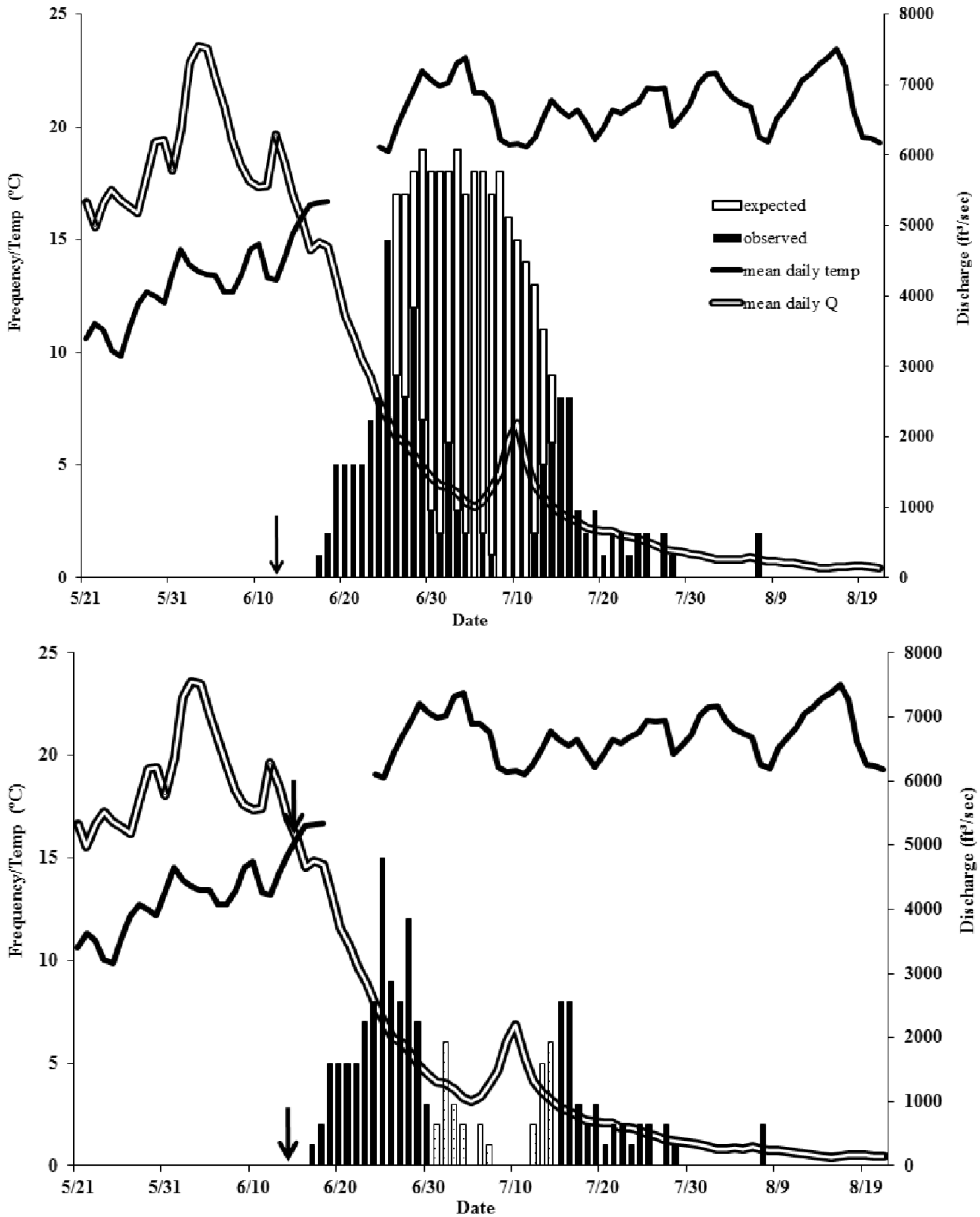

Figure 8. Conceptual histogram of distribution of hatching dates and abundance of smallmouth bass in the Yampa River, summer 2015 (upper panel), showing a mound-shaped distribution as normally occurs. Hatching dates are divided into early (left filled bars), middle (shaded), and late cohorts (right filled bars). The actual distribution of hatching dates and abundance from samples (lower panel) shows effects of a flow and turbidity event that peaked on 11 July, and removed most young smallmouth bass that were hatched at that time. Bass that survived during that flow and turbidity event also showed reduced growth.

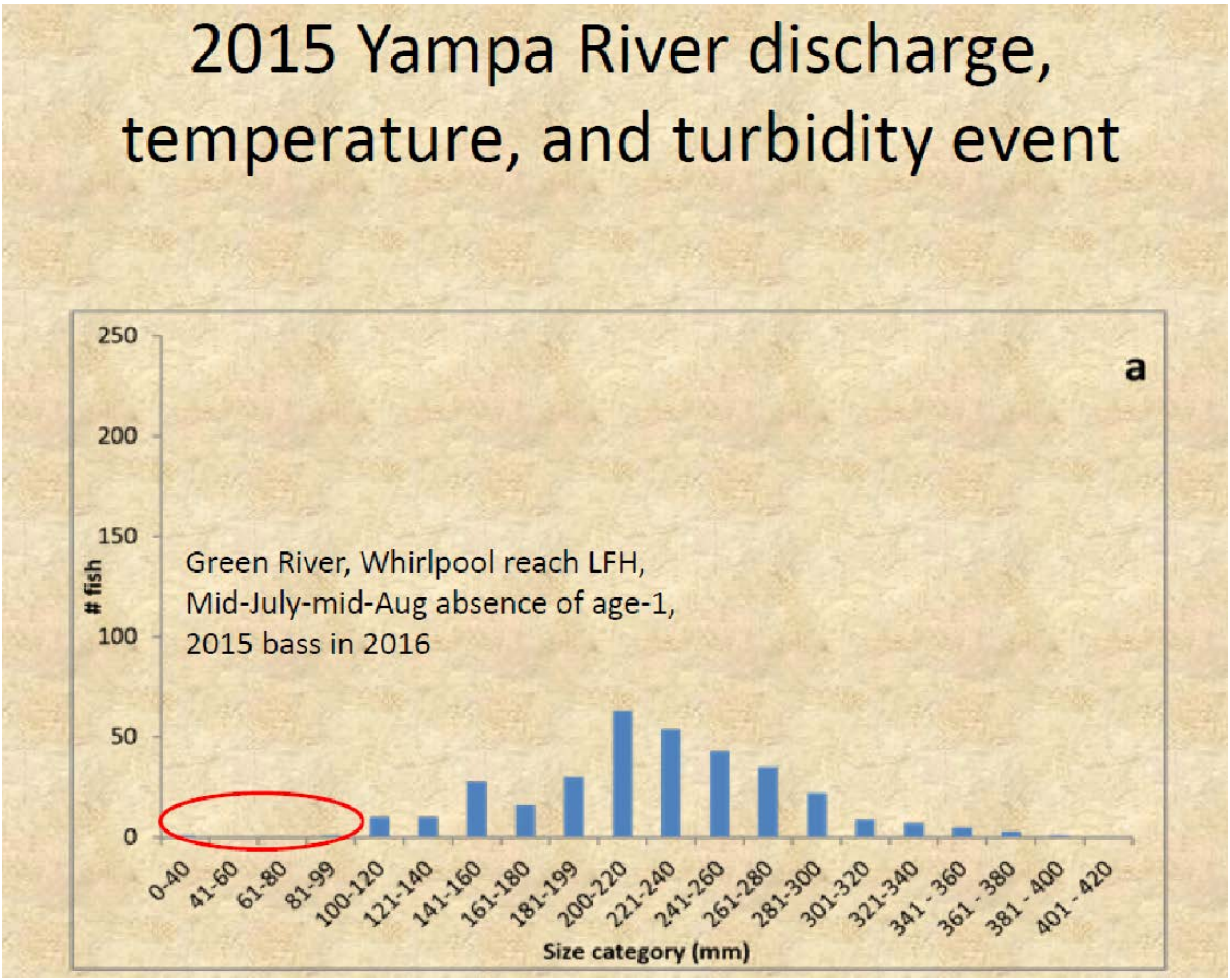

Figure 9. Length-frequency histogram for smallmouth bass captured in the Green River from Echo Park to Split Mountain, in the early portions of the 2016 sampling season and prior to hatching of age-0 bass. Absence of age-1 fish produced in 2015 is highlighted by the red oval, when in most years, those fish (< 100 mm TL) are abundant.

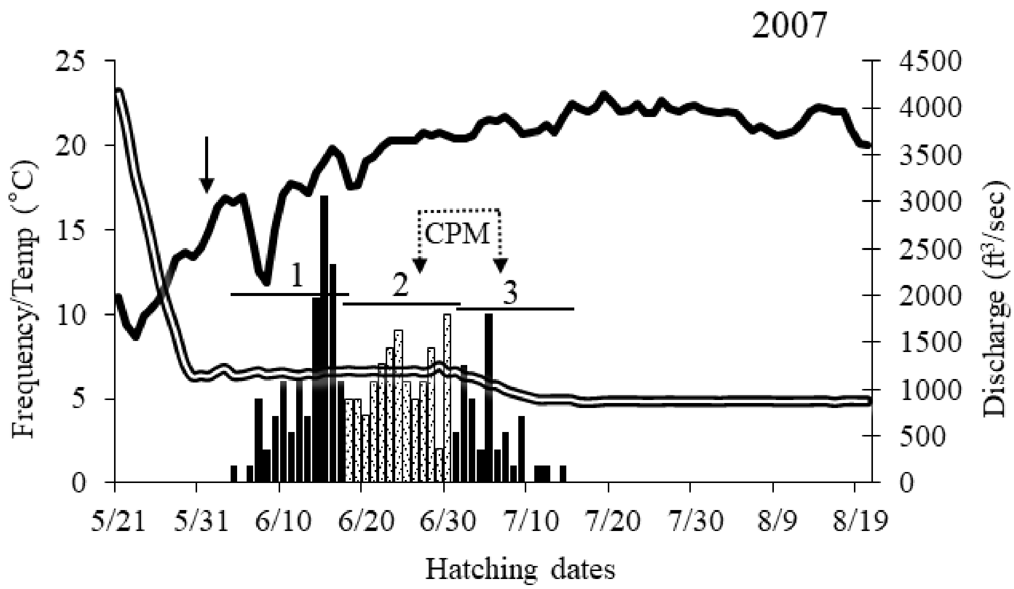

Figure 10. Distribution of hatching dates and abundance of young smallmouth bass in samples combined for the regulated (upstream of Yampa River) and partially regulated sections of the Green River (downstream), Colorado and Utah, 2007, to show the range of dates for hatching; flow and water temperature regimes are from the regulated upstream section. Hatching dates are divided into early (left filled bars), middle (shaded), and late cohorts (right filled bars). Solid vertical arrow indicates onset of 16°C water temperature in the upstream regulated reach, the over-numbered horizontal solid lines indicate temporal extent of 1st, 2nd, and 3rd hatching cohorts, and the dotted vertical arrows indicate dates of first capture of drifting Colorado pikeminnow (CPM) larvae hatched in the Yampa River and the first drift peak entering the Green River.

Appendix I. Considerations for conducting flow spike type experiments in other locations of the upper Colorado River basin.

Yampa River smallmouth bass management and study.—Although this study plan is focused on the regulated and partially regulated reaches of the Green River, some of the concepts may logically extend to other rivers in the area that have problematic smallmouth bass populations. Therefore, a few thoughts concerning Yampa River smallmouth bass control and evaluation may be useful because of the level of effort expended on fish removal there. Lack of substantial flow regulation on the Yampa River, other than that offered by Elkhead Reservoir, is a generally positive ecosystem attribute, but may limit ability of managers to effect control actions via flow manipulations on smallmouth bass in that system. Lower flows in summer also limit mechanical removal activities to periods of the year when flows are higher. That is because the Yampa River becomes less navigable at flows less than about 28.3 m^3/sec (1,000 ft^3/sec) by large boats that are efficient at bass removal, although boating is possible at slightly lower flows with experienced operators. That flow level typically occurred about the time that Cohort 1 fish were finished hatching in the Yampa River (see distributions of hatching dates, Figure 5). Thus, widespread mechanical removal and nest disruption activities are possible mostly prior to then.

Additional Yampa River removal efforts might include targeted angling or electrofishing to capture aggressive males defending nests, with emphasis on extending this later into the summer to help remove males that protect young fish produced in later cohorts. Direct disruption of nests may also be effective (Loppnow et al. 2013) using devices to disturb nest contents (e.g., rakes, water jets). Another possible means to induce a disturbance and disrupt nesting success is flow manipulations from Elkhead Reservoir. Such a practice will necessarily have to occur when Yampa River flows were quite low, perhaps 14.2 m^3/sec (500 ft^3/sec) or less, and only if relatively high flow releases could be arranged, perhaps up to the outlet maximum capacity of Elkhead Reservoir of about 14.2 m^3/sec. This is because supplemented flow volumes will have to be high to increase flow velocities substantially in the main channel Yampa River, a main factor in disrupting spawning and hatching success (Smith et al. 2005). The flow rating curve data for the Maybell USGS gauge (#09251000) showed water stages at flow levels of 7.1, 14.2, 21.2, 28.3 m^3/sec (250, 500, 750, and 1000 ft^3/sec) were 56, 72, 84, and 115 cm (1.85, 2.37, 2.76, and 3.08 feet) respectively. Thus, a baseflow of 7.1 m^3/sec in the Yampa River increased to 14.2 m^3/sec, will result in a stage change of 16 cm (0.52 ft), with unknown changes in velocity or turbidity in locations where smallmouth bass nests are located. A baseflow of 14.2 m^3/sec (500 ft^3/sec) increased by that same flow to 28.3 m^3/sec (1000 ft^3/sec) will result in a stage change of 22 cm (0.71 feet). Low flow years typically produce large year classes of larger fish, so undertaking a flow disturbance in such years will be timely and allow the disturbance flow to be large relative to baseflow. A flow increase may alter conditions in spawning areas to the point that eggs and weak-swimming larvae are swept away, or may encourage adults to abandon nests. Attempting a flow disturbance at higher baseflow levels will not be likely to succeed because river stage and velocity changes possible with a 14.2 m^3/sec (500 ft^3/sec) increase, when baseflows are at 28.3 m^3/sec (1,000 ft^3/sec) or higher, will not likely be substantial enough to alter habitat or flows in a meaningful way.

Understanding effects of Yampa River flow disturbances requires an assessment of physical effects of increased flows, in addition to a biological investigation, regardless of the reach involved, so many of the monitoring considerations for the Yampa River evaluation are the same as for the Green River as described earlier. Biological measures of effects of flow or temperature disruptions might include assessments of pre- and post-disturbance egg or larvae presence in nests, marking of male-guarded nests, and observations of male behavior on nests. This approach could also be used to evaluate effects of disturbance from sampling during increased late spring sampling to remove nesting smallmouth bass, where removal or displacement of adults might result in reduced nest success. Observations might also include abundance of newly dispersed smallmouth bass larvae that occupy low velocity areas, in both pre- and post-disturbance periods. A longer-term assessment will also include estimates of abundance of various life stages (Project 125; Bestgen et al. 2007b), and abundance of age-0 fish in autumn (Project 140 results), in locations such as Little Yampa Canyon. That reach has a long history of sampling, both for smallmouth bass as well as for native and other small-bodied fishes that might respond to bass removal, and should be included in an assessment of disturbance effects designed to reduce smallmouth bass reproductive success. Ideally, other reaches where disturbances will be initiated will have similar background data.

The approach described above to implement and evaluate flow disturbance effects could also be used as a template to evaluate use of flow or sediment releases in other systems of the upper Colorado River to combat negative effects of invasive smallmouth bass. For example, flow releases to limit smallmouth bass reproduction and recruitment have been considered for the Dolores River (Bestgen et al. 2011b) and effects were opportunistically evaluated along with other flow-related stream characteristics as recently as summer 2017. Evaluation of results of that effort are not yet available, but other opportunities may exist where flow and sediment releases can be controlled and released downstream at appropriate times. A flow release from Kenney Reservoir on the White River for algae control was also implemented in July 2018, which is briefly described in the Project 140 annual report. Other factors to consider when evaluating other locations for management include: 1) densities of young and adult smallmouth bass in the downstream reach; 2) knowledge of specific spawning sites and timing of reproduction; 3) field accessibility; 4) magnitude of the flow spike possible from releases; and 5) other resources impacted by a flow or sediment spike (hydropower, downstream fishery, negative sediment effects, vegetation). Opportunities for mutually beneficial releases that, for example, combine routine sediment flushing from behind diversion dams with nonnative fish management may be possible, pending resolution of details such as appropriate timing and duration of such operations.