Hydrologic Evaluation of Smallmouth Bass Spawning Sites in the Upper Green River Using LiDAR

Environmental Science Division

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EXECUTIVE SUMMARY

The smallmouth bass has been considered one of the most problematic invasive species in the upper Colorado River basin. As a predator of larval fish and juveniles, this nonnative species is an impediment to conservation efforts for endangered fish species of the Colorado River basin including Colorado pikeminnow (*Ptychocheilus lucius*), razorback sucker (*Xyrauchen texanus*), humpback chub (*Gila cypha*), and bonytail chub (*Gila elegans*). Several measures have been recommended to control smallmouth bass populations to conserve the endangered fish species. Among these measures are efforts to control flows during the spawning season to disrupt smallmouth bass reproduction. Previous work has suggested that smallmouth bass spawning in areas of the Green River could be inhibited during higher flows from the Flaming Gorge Dam due to lack of suitable habitat.

Little research has been conducted to evaluate an optimal range of flow increases (“flow spikes”) needed to disrupt smallmouth bass reproduction in the Green River. Current research proposals to evaluate the effectiveness of flow spikes on controlling smallmouth bass reproduction target post-spawning flows of 4,500 cfs, maintained for three days, to inundate side-channel spawning habitats. In this report, we present results of a topographic study of smallmouth bass spawning sites in the upper Green River to characterize flow levels needed to inundate spawning habitats. This study used remotely sensed Light Detection and Ranging (LiDAR) data collected along the entire Green River, including channel margins and floodplain areas, to model water surface elevations and flow spikes needed to connect and inundate smallmouth bass spawning sites.

Using LiDAR data collected during the base flow period in 2015, hydrologic modeling was conducted to relate surface water elevation and flow in the Lodore Canyon and Island Park regions of the upper Green River. This modeling was then used to determine flows needed to connect backwaters considered likely to be suitable for smallmouth bass. A total of nine backwater habitats evaluated in this study were identified as potentially suitable for smallmouth bass spawning. Three of these sites were connected to the Green River main channel at base flows between 2,310 and 2,980 cfs. The remaining six potentially suitable smallmouth bass spawning sites connected with the Green River main channel at flows at or below power plant flows of 4,600 cfs (range: 3,276 – 4,600 cfs). Average bar inundation for each site, represented as the percentage of total side-channel sand or gravel bar inundated, was 44% (range: 6 – 82%) at power plant flows of 4,600 cfs and 68% (range: 24 – 100%) at bypass flows of 8,600 cfs. Minimum habitat depth was estimated as 0.5 ft and 3.1 ft at power plant and bypass flows, respectively.

This study illustrates the application of terrestrial LiDAR data to model topographic and hydrological relationships to support conservation efforts of the Colorado River endangered fish species. We were able to use these data to evaluate recommended flow targets for controlling the smallmouth bass population in the upper Green River basin. Side-channel terrestrial LiDAR data has the potential to serve additional purposes in evaluation of river habitat geomorphology, such as studies of floodplain wetland connection (e.g., Caruso et al. 2019), identification of terrace wetlands, and development of additional flow recommendations to improve habitat quality.

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1 INTRODUCTION

Invasive species pose major threats to native wildlife and their habitats. Over the past 100 years, non-native fish species have established populations in the upper Colorado River basin (Vanicek et al. 1970). Large-bodied predatory non-native smallmouth bass (*Micropterus dolomieu*) and northern pike (*Esox lucius*) were first recorded in the upper Green River in the early 1990s where they presumably colonized from the Yampa River (Breton et al. 2014). Since that time, the smallmouth bass has been considered one of the most problematic invasive species in the upper Colorado River basin because of the high population densities it has established and its predatory capabilities (Johnson et al. 2008). As a predator of larval fish and juveniles, the smallmouth bass is considered an impediment to conservation efforts for endangered fish species of the Colorado River basin, including Colorado pikeminnow (*Ptychocheilus lucius*), razorback sucker (*Xyrauchen texanus*), humpback chub (*Gila cypha*), and bonytail chub (*Gila elegans*) (Bestgen and Hill 2016).

Several studies have been conducted in the past 20 years to examine methods to control smallmouth bass in the upper Colorado River basin. One recommended control measure is to disrupt smallmouth bass reproductive success (Bestgen and Hill 2016). In the upper Colorado River basin, observations of smallmouth bass spawning locations have been made in side-channel backwaters and areas of low velocity with gravel or sand substrates (Hawkins et al. 2009). Periods of high flow during or shortly after smallmouth bass spawning can reduce the species' reproductive success by altering adult guarding behavior, physically sweeping eggs and larvae away from nests, reducing feeding success of young due to increased turbidity, and reducing growth rates by changing water temperature (Larimore 1975; Winemiller and Taylor 1982; O'Brien and Showalter 1993; Orth and Newcomb 2002). It has been hypothesized that smallmouth bass spawning in areas of the Green River could be inhibited during higher flows from Flaming Gorge Dam due to lack of suitable habitat (Bestgen and Hill 2016).

Bestgen and Hill (2016) described relationships between smallmouth bass spawning and the Green River flow regime. They observed most spawning occurred during the month of June, with hatching of eggs beginning in late June. However, little research has been conducted to evaluate an optimal range of flow increases ("flow spikes") needed to disrupt smallmouth bass reproduction in the Green River. Current research proposals to evaluate the effectiveness of flow spikes on controlling smallmouth bass reproduction in the Green River would target post-

spawning flows of 4,500 cfs, maintained for three days, to inundate side-channel spawning habitats (Bestgen 2018). A topographic assessment of suitable smallmouth bass spawning habitats would be useful to understand the physical characteristics of these habitats and to inform the selection of target flow spikes that would be suitable for connecting and inundating smallmouth bass spawning habitats.

In this report, we present the results of a topographic study of smallmouth bass spawning sites in the upper Green River to characterize the flow levels needed to inundate the spawning habitats. This study uses remotely sensed Light Detection and Ranging (LiDAR) data collected along the entire Green River, including channel margins and floodplain areas, to model the water surface elevations and target flow spikes needed to affect smallmouth bass spawning sites.

2 METHODS

LiDAR Data Collection

During late Fall of 2015 the Utah Division of Forestry, Fire & State Lands and the U.S. National Park Service acquired LiDAR data for approximately 152 mi² covering 680 river miles of the Colorado, Green, and Yampa River corridors in southeast and eastern Utah and northwestern Colorado (Figure 1). The LiDAR point cloud was collected at a density of 8 points/m². The LiDAR data were collected between 15 October 2015 and 5 November 2015 when the rivers were at a stage of low flow so as to maximize the amount of terrestrial surface area available for modeling. From the LiDAR point cloud, a 0.5m bare-earth digital elevation model (DEM) was produced and made publicly available at <https://gis.utah.gov/data/elevation-and-terrain/2015-lidar-rivers/>.

This study focused on two particular reaches of the Green River downstream of Flaming Gorge Dam (Figure 1):

- Lodore Canyon, from approximately RM 242 to RM 225 in Colorado
- Island Park, from RM 215 to RM 208 in Utah

The specific dates of LiDAR collection were needed to establish reliable reference flow conditions for these locations. Based upon flight records provided by the LiDAR vendor¹, the Island Park reach was flown on 29 October 2015 and the Lodore Canyon reach was flown on 30 October 2015. This information was used to identify reference flow conditions for the Green River at the USGS gage stations nearest to each location (Table 1). For the Lodore Canyon reach, the mean daily Green River flow at the Greendale gage (USGS Gage 09234500) was approximately 2,310 cfs (range: 1,710 – 3,060 cfs) at the time of LiDAR collection. For the Island Park reach, mean daily Green River flow at the Jensen gage (USGS Gage 09261000) was approximately 2,980 cfs (range: 2,750 – 3,210 cfs) at the time of LiDAR collection. The daily mean hydrograph at the time of LiDAR collection for both gages is presented in Figure 2.

¹ The LiDAR vendor was Aerial Surveys International (<http://aerialsurveysintl.com>).

Figure 1. Distribution of LiDAR Collection Along the Colorado, Green, and Yampa Rivers in Utah and Colorado.

Table 1. Green River Flows at the Time of LiDAR Data Collection.

Gage (Site)	Green River Flow (cfs)
USGS Greendale Gage 09234500 below Flaming Gorge Dam (Used for Lodore Canyon locations)	2,310
USGS Jensen Gage 09261000 (Used for Island Park locations)	2,980

Figure 2. Mean Daily Flow Hydrograph for the Green River and Yampa River During the Period of LiDAR Data Collection. The brown line represents flow at the Greendale gage; the blue line represents flow at the Jensen gage. The shaded region represents the period of LiDAR data collection.

Identification of Smallmouth Bass Spawning Sites

Using a combination of LiDAR data and aerial imagery as observed through Google Earth, the entire Green River reach between Lodore Canyon and Island Park was reviewed to identify potential side-channel backwater habitats that might be suitable for smallmouth bass spawning. On April 27, 2018, we reviewed these locations using Google Earth imagery with Kevin Bestgen (a researcher at Colorado State University who has familiarity with smallmouth bass spawning habitats in study reach) to identify the locations where smallmouth bass have previously been observed (LaGory et al. 2018). The review consisted of visual inspection of Google Earth imagery along the Green River within Lodore Canyon and Island Park to locate areas where smallmouth bass spawning activity was previously recorded. In total, 17 potential sites were identified, of which there were 9 sites that were classified suitable spawning locations for smallmouth bass (Figure 3). A summary of these sites is provided in Table 2.

Using the LiDAR data, the water surface elevation was delineated for each site to determine whether the potential spawning sites existed as disconnected backwater habitats or whether these sites were already connected to the main channel during the period of LiDAR collection. Water surface elevation was determined by inspecting break points in the LiDAR DEM histogram and by LiDAR elevation values for known surface water in the main channel. An example illustration of how the LiDAR histogram was used to identify water elevation values is shown in Figure 4. Only the nine potentially suitable smallmouth bass spawning sites were evaluated at this step. Maps of water surface elevation at the time of LiDAR data collection (hereafter referred to as the reference stage) for all potential smallmouth bass spawning sites are shown in Appendix A. An example map illustrating the LiDAR-derived water surface elevation at site LC03 is shown in Figure 5. Based on the LiDAR-derived surface water elevations, six of the suitable spawning sites were not connected to the river main channel at the time of LiDAR data collection (Table 2). These 6 sites are LC03, LC06, LC08, LC09, IP01, and IP03.

Modeling Spawning Habitat Characteristics

At the six potentially suitable spawning sites that were not completely connected between the upstream and downstream ends (i.e., flow-through) to the Green River main channel at the time of LiDAR data collection, we utilized LiDAR to model the topography and surface water elevations associated with Green River flow. We used stage tables provided by USGS to determine stage-discharge relationships for the Greendale and Jensen gages that were used to model stage and flow changes at each of the smallmouth bass spawning sites.

We first established the reference flow and stage conditions as the flow and stage at time of LiDAR collection. This involved matching the reference flows reported in Table 1 with the corresponding stages (ft) at each gage. Using the stage-discharge relationships, we modeled the surface water elevation at Green River flows along a continuum between reference flow conditions and Flaming Gorge Dam power plant bypass flows of up to 8,600 cfs. Bypass flows refer to releases between approximately 4,600 cfs and 8,600 cfs that utilize the dam's bypass tubes because they exceed the flow that can be released through the power plant itself (up to 4,600 cfs). Within this range of flows, we estimated surface water elevation, minimum depth

Figure 3. Potential Smallmouth Bass Spawning Sites Evaluated in the Upper Green River. A total of 17 sites were identified in this portion of the Green River, of which 9 were considered to be suitable spawning sites.

Table 2. Potential Smallmouth Bass Spawning Locations in the Upper Green River.

Site Name	Suitable? ¹	Connected? ²	Approximate Longitude / Latitude
Lodore Canyon			
LC01	N	—	-108.92561, 40.65595
LC02	N	—	-108.93466, 40.63863
LC03	Y	N	-108.95283, 40.60255
LC04	Y	Y	-108.96308, 40.59417
LC05	N	—	-108.96970, 40.59482
LC06	Y	N	-108.97797, 40.59518
LC07	N	—	-108.98312, 40.58340
LC08	Y	N	-108.97014, 40.56597
LC09	Y	N	-108.98426, 40.53213
Island Park			
IP01	Y	N	-109.12494, 40.51279
IP02	Y	Y	-109.12353, 40.51354
IP03	Y	N	-109.15953, 40.52345
IP04	Y	Y	-109.15739, 40.51656
IP05	N	—	-109.14198, 40.50866
IP06	N	—	-109.15409, 40.5046
IP07	N	—	-109.15858, 40.50502
IP08	N	—	-109.16858, 40.49951

¹ The suitability of each site for smallmouth bass spawning was determined in consultation with Kevin Bestgen, Colorado State University, on April 27, 2018 (LaGory et al. 2018).

² Determination of whether a potential spawning site was connected to the river main channel was based on water elevations at the time of LiDAR data collection (i.e., reference stage). Sites that were deemed unsuitable were not evaluated (noted with “—”).

Figure 4. Example LiDAR DEM Histogram for Smallmouth Bass Site LC08. Using the break points in this histogram, the water surface elevation was determined to be 5,095.96 ft. The water surface elevation was confirmed by visually inspecting LiDAR elevation values for the main channel of the river.

Figure 5. Map of Surface Water Extent at LC03 at the Time of Lidar Data Collection (Reference Stage).
Note: the site was not a flow through at the reference stage (30 October, 2015; mean daily flow: 2,310 cfs).

at the connection point, and relative amount of sand or gravel bar inundation. In particular, we focused on these physical habitat attributes at the following four water elevation stages:

- Reference stage (water stage or flow at the time of LiDAR collection)
- Connection stage (water stage or flow at which the backwater habitat connects with the Green River main channel).
- Power Plant Stage (water stage corresponding to a 4,600 cfs release from Flaming Gorge Dam)
- Bypass Stage (water stage value corresponding to a 8,600 cfs release from Flaming Gorge Dam)

To estimate the amount of habitat inundation at each stage, we used a Geographic Information System (GIS) to spatially delineate the sand or gravel bar from satellite imagery at each potential spawning site during the reference stage. We used the hydrographic model to estimate the amount of sand or gravel bar area of the connected side-channel inundated at each stage. In addition, we estimated the minimum water depth for each spawning site as the minimum change in depth at the connection point for each subsequent stage.

3 RESULTS

Summary statistics for the six suitable spawning sites evaluated in this study are provided in Table 3. These statistics include information on the reference stage and flow, connection stage and flow, and the stage at maximum power plant flows (4,600 cfs) and bypass flows (8,600 cfs). For all potentially suitable smallmouth bass spawning sites evaluated, our models indicated that connection with the Green River main channel occurred at or below power plant flows of 4,600 cfs (range: 3,276 – 4,600 cfs).

Estimates of sand or gravel bar inundation, represented as the percentage of total side-channel bar inundated, and minimum habitat depth are provided in Table 4 and Figure 6. The average bar size of all sites was 36,850 ft² (range: 20,000 – 54,300 ft²). At power plant flows of 4,600 cfs, average bar inundation was 44% (range: 6 – 82%) and the average minimum habitat depth was 0.5 ft (range: 0.0 – 1.0 ft). At bypass flows of 8,600 cfs, average bar inundation was 68% (range: 24 – 100%) and the average minimum habitat depth was 3.1 ft (range: 1.6 – 4.1 ft). As indicated in Figure 6, the rate of sand or gravel bar inundation varied among spawning sites. Some sites experienced a more rapid rate of sand or gravel bar inundation following habitat connection, indicating a lower average sand or gravel bar elevation compared to other spawning sites that had a slower rate of bar inundation (greater average sand or gravel bar elevation).

Table 3. Summary Statistics for the Six Suitable Smallmouth Bass Spawning Sites Analyzed in this Study. All elevations are in feet above mean sea level.

Site	Reference Water Elevation (ft)	Reference Flow (cfs) ¹	Connection Water Elevation (ft)	Connection Flow (cfs)	Water Elevation at Power Plant Flow (4,600 cfs)	Water Elevation at Bypass Flow (8,600 cfs)
Lodore Canyon						
LC03	5,175.51	2,310	5,176.33	3,446	5,177.28	5,179.95
LC06	5,129.59	2,310	5,130.95	3,970	5,131.36	5,134.03
LC08	5,094.66	2,310	5,095.70	3,714	5,096.43	5,099.10
LC09	5,067.27	2,310	5,067.95	3,276	5,069.04	5,071.71
Island Park						
IP01	4,958.50	2,980	4,959.25	4,400	4,959.34	4,960.93
IP03	4,943.30	2,980	4,944.16	4,600	4,944.16	4,945.81

¹ Mean daily flow for 10/29/15 (Island Park) and 10/30/15 (Lodore Canyon) representing the flow at the time of LiDAR collection.

Table 4. Summary of Sand or Gravel Bar Inundation at the Six Suitable Smallmouth Bass Spawning Sites Analyzed in this Study.¹

Site	Maximum Bar Area ²	Percent Bar Inundation at Connection ³	Percent Bar Inundation at Power Plant Flow (4,600 cfs)	Minimum Habitat Depth (ft) at Power Plant Flow (4,600 cfs) ⁴	Percent Bar Inundation at Bypass Flow (8,600 cfs)	Minimum Habitat Depth (ft) at Bypass Flow (8,600 cfs) ⁴
LC03	23,000 ft ²	24%	82%	0.9	100%	4.0
LC06	24,500 ft ²	36%	54%	0.4	96%	3.5
LC08	46,500 ft ²	66%	69%	0.6	98%	3.7
LC09	54,300 ft ²	22%	37%	1.0	49%	4.1
IP01	20,000 ft ²	6%	6%	0.1	24%	1.7
IP03	52,800 ft ²	15%	15%	0.0	43%	1.6

¹ Refer to Appendix A for maps of each site at reference, connection, power plant, and bypass flows.

² Maximum sand or gravel bar area digitized at reference flows.

³ Refer to Table 3 for connection flows.

⁴ Minimum habitat depth refers to the change in depth at the connection point at power plant flow (4,600 cfs) and bypass flow (8,600 cfs).

Figure 6. Sand or Gravel Bar Inundation Graphs for the Six Suitable Smallmouth Bass Spawning Sites Analyzed in this Study.

4 CONCLUSIONS

We recorded a total of 9 potentially suitable smallmouth bass spawning sites in the Lodore Canyon and Island Park reaches of the Green River (Table 2). Our topographic assessment of 2015 LiDAR data within these reaches suggests that all of these suitable spawning sites connect to the Green River main channel at flows at or below power plant capacity (4,600 cfs). This finding supports the recommendations by Bestgen (2018) that post-spawning target flows of 4,500 cfs or greater might be needed to inundate the spawning sites and disrupt smallmouth bass reproduction. For the 6 spawning sites we included in our hydrographic model, the minimum habitat depth at power plant capacity ranged between 0 and 1.0 ft. At bypass flow (8,600 cfs), the minimum habitat depth increased by between 1.6 and 4.1 ft. These results suggest that temperature alteration and habitat scouring might be accomplished for some of these sites at power plant capacity flows (e.g., LC03, LC09), whereas other sites might require flows slightly above power plant capacity to achieve connection with the main channel that might result in habitat depths and velocities capable of mobilizing sediments associated with spawning areas, to destroy or flush eggs and larvae, or to alter temperature regimes and turbidity to decrease smallmouth bass reproductive success. However, the potential for disruption of spawning success due to increased sediment movement or velocity are speculative since the model results presented in this study have not been validated with field-based observations and within-habitat velocity evaluations were not performed.

While this study examined the topographic relationships of smallmouth bass spawning sites with Green River flow, this study did not consider other hydrologic aspects that could influence the suitability of these sites for smallmouth bass. For example, additional detailed hydrologic modeling could assist in determining the flow velocities that would occur within the side channel habitats at each stage in order to determine the potential disturbance to spawning, eggs, and/or larvae. In addition, more detailed hydrologic modeling could be used to assess the influence of timing and duration of target flows on spawning disruption.

This study illustrates the application of terrestrial LiDAR data to model topographic and hydrological relationships to support conservation efforts of the Colorado River endangered fish species. We were able to use these data to evaluate flow targets that have been recommended for controlling the smallmouth bass population in the upper Green River basin. Side-channel terrestrial LiDAR data has the potential to serve additional purposes in the evaluation of river habitat geomorphology, such as studies of floodplain wetland connection (e.g., Caruso et al. 2019), identification of terrace wetlands, and development of additional flow recommendations to improve habitat quality.

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APPENDIX A:

Maps and Images of Smallmouth Bass Spawning Sites in the Upper Green River

Figure A-1. Lodore Canyon Site #1 (LC-01) at the time of LiDAR collection (30 October, 2015). This site was determined to be unsuitable for smallmouth bass spawning and was therefore omitted from the habitat assessment.

Figure A-2. Lodore Canyon Site #2 (LC-02) at the time of LiDAR collection (30 October, 2015). This site was determined to be unsuitable for smallmouth bass spawning and was therefore omitted from the habitat assessment.

Figure A-3. Lodore Canyon Site #3 (LC-03) at A) the reference stage (2,310 cfs), B) connection stage (3,446 cfs), C) power plant capacity (4,600 cfs), and D) bypass flow (8,600 cfs).

Figure A-4. Lodore Canyon Site #4 (LC-04) at the time of LiDAR collection (30 October, 2015). This site was already connected at the time of LiDAR collection and was therefore omitted from the habitat assessment.

Figure A-5. Lodore Canyon Site #5 (LC-05). This site was determined to be unsuitable for smallmouth bass spawning and was therefore omitted from the habitat assessment.

Figure A-6. Lodore Canyon Site #6 (LC-06) at A) the reference stage (2,310 cfs), B) connection stage (3,970 cfs), C) power plant capacity (4,600 cfs), and D) bypass flow (8,600 cfs).

Figure A-7. Lodore Canyon Site #7 (LC-07). This site was determined to be unsuitable for smallmouth bass spawning and was therefore omitted from the habitat assessment.

Figure A-8. Lodore Canyon Site #8 (LC-08) at A) the reference stage (2,310 cfs), B) connection stage (3,714 cfs), C) power plant capacity (4,600 cfs), and D) bypass flow (8,600 cfs).

Figure A-9. Lodore Canyon Site #9 (LC-09) at A) the reference stage (2,310 cfs), B) connection stage (3,276 cfs), C) power plant capacity (4,600 cfs), and D) bypass flow (8,600 cfs).

Figure A-10. Island Park Site #1 (IP-01) at A) the reference stage (2,980 cfs), B) connection stage (3,276 cfs), C) power plant capacity (4,600 cfs), and D) bypass flow (8,600 cfs).

Figure A-11. Island Park Site #2 (IP-02) at the time of LiDAR collection (29 October, 2015). This site was already connected at the time of LiDAR collection and was therefore omitted from the habitat assessment.

Figure A-12. Island Park Site #3 (IP-03) at A) the reference stage (2,980 cfs), B) connection stage (4,600 cfs), C) power plant capacity (4,600 cfs), and D) bypass flow (8,600 cfs).

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