DRIFT AND RETENTION OF FLANNELMOUTH SUCKER *CATOSTOMUS LATIPINNIS*, BLUEHEAD SUCKER *CATOSTOMUS DISCOBOLUS*, AND WHITE SUCKER *CATOSTOMUS COMMERSONII* IN THE BIG SANDY RIVER, WYOMING

BY

KOREEN A. ZELASKO, KEVIN R. BESTGEN, AND KEVIN HAYES
LARVAL FISH LABORATORY
DEPARTMENT OF FISH, WILDLIFE, AND CONSERVATION BIOLOGY
COLORADO STATE UNIVERSITY
FORT COLLINS, CO 80523

FINAL REPORT
TO
WYOMING GAME AND FISH DEPARTMENT
LARVAL FISH LABORATORY CONTRIBUTION 165

SEPTEMBER 2011

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Big Sandy River, a tributary to the Green River in southwest Wyoming, supports populations of rare flannelmouth sucker *Catostomus latipinnis* and bluehead sucker *Catostomus discobolus*, catostomids native to the Upper Colorado River Basin. Big Sandy Reservoir impounds the river and may be a source of non-native species detrimental to native catostomids. A proposed barrier to upstream movement of non-native species from the reservoir may also prevent upstream movement of native catostomids that drifted into the reservoir as larvae. The primary goals of this study were to determine the abundance of flannelmouth and bluehead sucker larvae that drift into Big Sandy Reservoir, which may be lost to the riverine population, and to determine abundance of larvae and juveniles retained upstream of the reservoir, given their importance to maintain adult populations. Secondary goals of the study were to calculate larval fish species composition, estimate catostomid spawning periods and locations, describe recruitment, and assess degree of native catostomid hybridization with white suckers.

Drift net sampling was conducted in late spring and summer 2009 and 2010 at stations BS1, BS2, and BS3, which were arrayed longitudinally 4.0, 18.3, and 45.2 km upstream of a gauging station just upstream of the reservoir, respectively, in order to detect spatial differences in species composition and abundance in the Big Sandy River. After discharge levels dropped in late summer, we seined low-velocity areas to determine relative abundance and density of sucker larvae and juveniles still present in the system. Drift netting resulted in 1112 catostomid larvae (10.2/hour) captured in 2009 and 509 catostomid larvae (3.3/hour) in 2010. Mean catch per hour was highest at station BS1 in 2009 (13.4 catostomids/hour) but highest at BS3 in 2010 (4.6 catostomids/hour). In combined samples from all larval drift stations, flannelmouth sucker was the most abundant catostomid captured in 2009 (60% of suckers), while white sucker *Catostomus commersonii* was most abundant in 2010 (53% of suckers). Bluehead sucker made up the smallest percentage of catostomids captured in both 2009 and 2010 (15 and 8%, respectively). In 2009, 89% of flannelmouth suckers were captured at downstream station BS1 and that species made up 73% of catostomids at that site. Station BS1 produced most captures of white sucker (64%), while BS2 produced most bluehead sucker captures (59%). In 2010, flannelmouth suckers made up similar proportions of each station's catostomid capture, and were most often captured at lower station BS1 (64%). Approximately 76% of white suckers in 2010 were captured at BS1. Only 41 bluehead suckers were captured in 2010 drift sampling and over half were from upstream station BS3; preponderance of bluehead sucker larvae at stations BS2 and BS3 in 2009 and 2010, respectively, suggested some level of longitudinal separation of species. Based on extrapolation of fish densities in samples to stream flow levels when sampling occurred, we estimated nearly 1,350,000 flannelmouth suckers and 52,000 bluehead suckers may have drifted downstream past station BS1 and into Big Sandy Reservoir from 16 June through 7 August 2009. At least 147,000 flannelmouth suckers and 10,000 bluehead suckers may have drifted into the reservoir from 8 June through 30 July 2010. Higher abundance of the more common flannelmouth sucker nearest the reservoir indicated that species may be most affected by a barrier. Fewer bluehead suckers were captured downstream (5.0% and 3.5% of BS1 catostomids in 2009 and 2010, respectively), which suggested that species may be less affected by a barrier, although it is much more rare than flannelmouth sucker. Spring run-off flows in 2009 and 2010 were higher than the historical average and may have increased downstream drift rates.

Based on temperature-dependent embryo incubation and larval growth rates, we calculated peak 2009 spawning periods of 30 April–18 May for flannelmouth sucker and 15 May–3 June for bluehead sucker. Mean daily water temperature during combined peak spawning for both species in 2009 (30 April–3 June) was 9.2°C or lower, compared to 10.2°C and 11.2°C for the same period in 2005 and 2006, respectively (Wyoming Game and Fish Department, unpublished data). Peaks were similarly timed in 2010: 3–20 May for flannelmouth sucker and 16 May–8 June for bluehead sucker, but with mean daily water temperatures of 8.6°C and 11.0°C, respectively. White sucker peak spawning periods were longer than those of native suckers both years: 13 May–9 June in 2009 and 9 May–4 June in 2010. The timing of captures among years (toward the end of peak runoff in 2009 and well after the peak in 2010) along with the timing of most captures at each station (earlier at downstream BS1 and later at upstream BS3), illustrated that thermal characteristics may be more important as spawning cues than discharge levels. Spawning date estimates were dependent upon multiple assumptions, due to lack of well-documented, species-specific incubation times and growth rates at the low temperatures observed in the Big Sandy River during spring.

We conducted drift simulation trials at both a low-gradient downstream site and a high-gradient upstream site by releasing semi-buoyant beads at various flow levels to determine transport rates and calibrate drift net captures of larvae at flow levels other than those observed in this study. Percent of beads captured per trial was low at both sites (<0.1–3.6%) compared to percent of water volumes sampled, even though transport distances were short: 5.0 km at the low-gradient site and 6.4 km at the high-gradient site. Consequently, use of water volumes sampled to predict numbers of larvae drifting past station BS1 may have resulted in overestimation of larvae lost to the reservoir. Transport rates were higher at the low-gradient site for most discharge levels. Mean velocities of captured beads were higher during high-gradient trials than low-gradient trials at most discharge levels, but few or no beads reached the high-gradient drift nets during the lowest discharge trials. The river is markedly more sinuous in the high-gradient portion, which caused beads to become deposited in pools and low-velocity, near-shore areas and likely aids in retention of bluehead sucker larvae spawned in upstream reaches (assuming beads and fish drift similarly). The physical nature of the Big Sandy River complicated estimation of our sampling efficiency, but trials provided valuable insight into the unknown behavior of drifting larvae in the system.

Abundance and density of catostomids in seine samples varied by species, season, location, and year. White sucker was captured in higher proportions than native catostomid species at nearly all locations in both 2009 and 2010. Young-of-the-year (YOY) catostomid densities among mainstem locations upstream of the gauging station in 2009 were highest in seine samples collected near site BS2 (a location noted to have more channel complexity than others). In 2010, bluehead sucker density was highest at BS3 during August, while flannelmouth and white sucker densities were highest at BS2 during July. Densities of all species at mainstem locations upstream of the gauging station generally decreased between August and October sampling in both years. In Big Sandy Reservoir in July 2010, we found a high mean density of white sucker (7.1/m^2, range: 0.1–32.5/m^2) and no native suckers. Low bluehead sucker abundance in the reach downstream of the gauging station in 2010 suggested either relatively low transport rates or poor survival of those fish. More flannelmouth suckers were found in that reach that at some upstream locations that year; but it is unlikely that they moved upstream from the reservoir, as none were found in reservoir seine samples. Therefore, installation of a barrier may have minimal effects on native sucker populations, especially if abundant white suckers in the reservoir move upstream and negatively affect native catostomids.

The ratio of native flannelmouth and bluehead suckers to non-native white suckers in 2009 drift samples was 3:1, but only 1:1 in later seine samples, suggesting a lack of recruitment in native sucker populations. However, we observed the opposite trend in 2010: the ratio of native suckers to non-native suckers in drift samples approached 1:1, but native suckers outnumbered white suckers by a 2:1 ratio in seine samples upstream of the gauging station that year. Variation in juvenile abundance as observed in this study can be influenced by many factors, including concurrent non-native species removal, predation, and discharge. An extended and more uniformly productive spawning period may make white sucker less susceptible to episodic recruitment failure. Protracted high flows in 2009 may have transported more larvae downstream into Big Sandy Reservoir than average flows (or even a single, higher-than-average peak, such as in 2010), resulting in lower mean young-of-year densities for all species in seine sampling. Continued drift and seine sampling in more average water years will help managers better understand implications of potential non-native fish management actions and provide useful baseline ecological information for these catostomid populations living at the northernmost portion of their ranges under a variety of hydrologic conditions.

List of Tables

Page

List of Figures

Introduction

Flannelmouth sucker *Catostomus latipinnis* and bluehead sucker *Catostomus discobolus* are catostomids native to the Colorado River Basin. While once widespread and abundant, the species now occupy 50% or less of their Upper Colorado River Basin ranges (Bezzerides and Bestgen 2002). Habitat alterations and non-native species introductions are primary causes of decline of native fishes in western rivers (Petts 1984; Carlson and Muth 1989; Minckley and Deacon 1991; Stanford et al. 1996; Poff et al. 1997; Olden et al. 2006). Both species are listed as "species of greatest conservation need" in Wyoming (Wyoming Game and Fish Department 2010) and "species of concern" in Utah, and flannelmouth sucker is also a "species of special concern" in Colorado (Utah Division of Wildlife Resources 2006).

In Wyoming, bluehead sucker was historically rare throughout its range. Some exceptions include Muddy Creek in the Little Snake River drainage, where it was once widely distributed and relatively common but faces increased threats of habitat fragmentation and hybridization with non-native white sucker *Catostomus commersonii* (Compton 2007), as well as parts of the Green River, where it was abundant prior to a rotenone treatment in 1962 (Baxter and Stone 1995). The species rebounded in the Green River, but has since declined in its native range (Wheeler 1997; Weitzel 2002a; Gelwicks et al. 2009). During recent surveys (2002–2006), bluehead sucker was not found in several sub-drainages where it was previously documented, but putative hybrids with white sucker were collected (Gelwicks et al. 2009). Flannelmouth sucker was historically abundant throughout the Green River Basin, but has likewise declined throughout that range and may have been extirpated from Savery and Jack Morrow creeks (Gelwicks et al. 2009). The Wyoming Game and Fish Department (WGFD, 2010) classifies both species as NSS1: populations are physically isolated and/or extremely low densities throughout historic range; extirpation appears possible; habitat declining or vulnerable. As in the rest of the Upper Colorado River Basin, habitat alterations (dams, irrigation diversions, and water quality) and introductions of non-native species (with subsequent predation and hybridization) are cited as major threats to persistence of flannelmouth and bluehead sucker (Weitzel 2002a; Miller and Weitzel 2003; Gelwicks et al. 2009). Hybridization with non-native white sucker, in particular, greatly imperils the species in Wyoming (Weitzel 2002a).

In response to documented declines, Wyoming is a signatory to a multi-agency conservation agreement and strategy for roundtail chub G*ila robusta*, bluehead sucker, and flannelmouth sucker (Utah Division of Wildlife Resources 2006), the goal of which is to ensure the persistence of the three species' populations throughout their ranges. A state management plan for the three species has been formulated (Senecal et al. 2009) and identifies priority management sub-drainages based on species' distribution and status: Muddy Creek, Big Sandy River, Little Sandy Creek, Upper Bitter Creek, and the Finger Lakes. Big Sandy River, in particular, was chosen for its robust populations of bluehead and flannelmouth sucker, unique haplotypes of flannelmouth sucker, and low levels of hybridization with non-native catostomids (Douglas and Douglas 2007b; Douglas and Douglas 2007a; Gelwicks et al. 2009). No roundtail chub have been collected there since 1972 (Miller 1978). The Big Sandy River was subsequently identified as a top stakeholder-ranked Tier III watershed with potential to be managed as a native fish conservation area (Dauwalter et al. 2011). The primary management objectives in Big Sandy River are to maintain and restore habitat and to remove the threat of non-native fishes, principally white sucker and burbot *Lota lota*. Since its introduction to the Big Sandy River Basin sometime prior to 1970, white sucker has become pervasive (Miller 1978; Wheeler 1997; Weitzel 2002b; Gelwicks et al. 2009) and potential exists for increased hybridization with native catostomids, as observed in other parts of the Upper Colorado River Basin (Bestgen et al. 2007b; Douglas and Douglas 2007b). Burbot, which are native to the Wind River drainage in Wyoming (Hubert et al. 2008), were introduced into Big Sandy Reservoir between 1985 and 1995 (Sweet 2007), were positively identified in the river in the early 2000's (Gelwicks et al. 2009), and have subsequently increased in numbers (Atwood et al. 2011). Burbot are voracious, indiscriminate piscivores and influential competitors (Bailey 1972). Other non-native species in Big Sandy River include: longnose sucker *Catostomus catostomus*, lake chub *Couesius plumbeus*, redside shiner *Richardsonius balteatus*, and fathead minnow *Pimephales promelas*. All pose hybridization, competition, and/or predation threats to the native fish community, which includes speckled dace *Rhinichthys osculus*, mountain whitefish *Prosopium williamsoni*, mottled sculpin *Cottus bairdii*, and mountain sucker *Catostomus platyrhynchus*, in addition to bluehead and flannelmouth sucker.

While non-native species removal is a top management priority, it is recognized that renovation cannot be successful if source populations of non-native species continue to re-colonize the river from Big Sandy Reservoir. Construction of a barrier just upstream of the reservoir has been suggested to prevent re-colonization (Sweet 2007; Gelwicks et al. 2009); but potential impacts to native catostomids, including blocked access to preferred habitats and loss of larvae to reservoir, were identified as information needs. Although studies to investigate fish movement near the upstream end of the reservoir have begun (Atwood et al. 2011), little is known of native juvenile and adult sucker movement upstream out of the reservoir or larval sucker drift downstream into the reservoir. Downstream drift of larvae is potentially problematic if the main recruitment area for native suckers is the reservoir, which would be isolated from the upstream population if a barrier was installed.

GOALS AND OBJECTIVES

The primary goal of this study was to determine the abundance of flannelmouth and bluehead sucker larvae that drift into Big Sandy Reservoir, which may be lost to the riverine population. A related goal was to determine abundance of larvae and juveniles retained upstream of the reservoir, given their importance to maintain adult populations. Secondary goals of the study were to calculate larval fish species composition, estimate catostomid spawning periods (with associated hydrograph and water temperature monitoring) and locations, describe recruitment, and assess degree of native catostomid hybridization with white suckers.

Objectives to accomplish those goals included:

- Establishment of three drift net stations at various distances upstream of a proposed barrier location and sampling the duration of spawning and larval drift season to determine abundance of sucker larvae transported downstream.

- Release and recapture of known numbers of semi-buoyant beads upstream of drift stations at various flow levels to determine transport rates of drifting particles (e.g., larvae) and transport efficiency of the system, calibrate drift net captures of larvae at flow levels other than those observed in 2009, and assess sampling efficiency.

- Seine sampling in low-velocity areas of the Big Sandy River to compare relative abundance and density of native sucker larvae and juveniles present in the system following reproduction to other portions of the Upper Colorado River Basin where self-sustaining populations of the species are known to exist.

STUDY AREA

The Big Sandy River is a tributary to the Green River in the Colorado River Basin and is located in southwestern Wyoming (Figure 1) with headwaters in the Wind River Range. It drains approximately 4500 km^2 and flows into the Green River 40 km downstream of Fontenelle Reservoir (Miller 1978). The region is classified as arid to semi-arid desert, and streamflow upstream of Big Sandy Reservoir is a result of snowmelt runoff and summer precipitation (Figure 2). The dam at Big Sandy Reservoir regulates downstream flow.

The study area was bounded by U. S. Geological Survey (USGS) gauging station 09213500 (river kilometer [RK] 0, just upstream of Big Sandy Reservoir) and Buckskin Crossing, about 90 km upstream (Figure 3). Land adjacent to the river is mostly private (70%) and primarily used for livestock grazing and some farming (Sweet 2007; Senecal et al. 2009). Substrate is predominantly shifting sand with some shale and sandstone bank outcroppings (Miller 1978). A slight (0.02%) increase in gradient upstream of RK 36 results in more gravel and cobble substrate in the upstream portion of the Big Sandy River (Sweet 2007), which is also markedly more sinuous than downstream. Sculpin Creek, a perennial tributary, flows into Big Sandy River from the east at RK 45.3 and receives water from springs as well as from Little Sandy Creek (via the Long Draw irrigation diversion stream).

METHODS

Larval drift sampling

We established three drift net stations to monitor larval drift: BS1, BS2, BS3 (approximately 4.0 km, 18.3 km, and 45.2 km upstream of USGS gauging station 09213500, respectively; Figure 3). Sampling at BS1 took priority over all others, because it addressed the primary goal of the study: to determine if native catostomid larvae drift into Big Sandy Reservoir. Sampling at other stations was intended to detect any differences in distribution of larval drift and adult spawning activity among species. We occasionally collected drift net samples at other sites, i.e. Big Sandy River at Buckskin Crossing (in conjunction with *Drift Simulations*, below) and in Sculpin Creek.

Custom drift nets from Wildlife Supply Company measured 50 cm wide x 30 cm high x 1.0 m long with 560 µm mesh. At each station, two to three nets were submerged side by side with the first net adjacent to a bank or gravel bar shoreline. It has been suggested that Colorado River catostomids may actively drift closer to shorelines than mid-channel (Robinson et al. 1998). Each net was equipped with a General Oceanics Model 2030R flow meter. Nets were set for about one hour during each sampling session and primarily just after dawn or prior to dusk, times of moderate drift. Western catostomids and Colorado River catostomids, in particular, have been shown in some studies to drift in highest densities during hours of darkness and at lowest densities in the middle of the day (Carter et al. 1986; Ellsworth et al. 2010). Furthermore, Bestgen et al. (1998) demonstrated that dawn sets provided the most consistent estimates of larval Colorado pikeminnow abundance. Flow meter readings and times were recorded at the start and end of each net-set. Drift net samples were strained, preserved in 100% ethanol, and stored in plastic bags. Fish larvae and eggs were removed from samples within 1–24 hours for subsequent identification. Specimens were verified, measured in 0.5 mm total length (TL) increments, cataloged, and stored at the Larval Fish Laboratory, Colorado State University, Fort Collins, Colorado.

We calculated water velocities and volumes sampled during each session with the following equations adapted from those provided by General Oceanics:

(1) $\text{DISTANCE (m)} = \frac{\text{difference in flow meter readings} \times 26{,}873}{999999}$

(2) $\text{SPEED (cm/s)} = \frac{\text{DISTANCE (m)} \times 100}{\text{time (s)}}$

(3) $\text{VOLUME (m}^3\text{)} = \text{net mouth area (m}^2\text{)} \times \text{DISTANCE}$, where net mouth area = $0.15\ m^2$

Minimum, maximum, and mean discharge levels (in cubic feet per second, cfs) of the Big Sandy River during each sampling session were obtained from USGS gauge 09213500, located immediately upstream of Big Sandy Reservoir. Discharge data was converted to metric units for analyses (1 cfs = 0.0283 m^3/s). Water temperatures (in degrees Celsius, °C) during each sampling session were taken by hand-held thermometer.

Numbers of native catostomids that drifted past downstream station BS1 and, presumably, into Big Sandy Reservoir between dates of first and last captures of each species were estimated using numbers captured during net sets, extrapolation to 24-hour periods, and interpolation for days when no sampling occurred. More specifically:

(4) $\text{\# past BS1/hour} = \left(\frac{100}{\text{\% of river volume sampled}}\right) \times \text{\# captured/hour}$

(5) # past BS1/24 hours = # past BS1/hour × 24

The above equations assume that larvae were distributed uniformly and drifted at the same rate as water flowed.

For days when no sampling occurred, we interpolated numbers of each species drifting past station BS1 using the "# past BS1/24 hours" calculated for the nearest day before and after the missing values. The difference between those days (starting value – ending value) was divided by the number of missing days and that increment was added to or subtracted from the starting value to reach the ending value. Interpolation was employed sparingly (on 4–13 d of the entire 53-d sampling period each year) and only for days during periods of consistent captures of each species (no intervening sampling days with zero captures) for the most conservative estimates.

Spawning season

To characterize the spawning periods of catostomids in Big Sandy River, we back-calculated hatching and spawning dates from lengths of larvae captured during drift net sampling. Approximate hatch dates were first estimated using length-age relationship equations calculated for bluehead and flannelmouth sucker larvae captured by seine in 2004 in the Green River, Colorado, from Browns Park National Wildlife Refuge to just upstream of the Yampa River confluence. That batch of larvae was captured at the same time of year as those collected in this study and was of similar size. The Green River at Browns Park and the Big Sandy River have displayed similar thermal regimes during catostomid incubation and drift (Figure 4). The 2004 larvae were measured (mm TL); otoliths were extracted and prepared as needed (mounted and sanded in some cases); and daily increments were counted to determine ages. Linear regression was used to fit a relationship between TL and age for each species (Figure 5, K. Bestgen, unpublished data):

(6) bluehead sucker: $y = 59.865*\ln(x) – 139.98$

and

(7) flannelmouth sucker: $y = 76.535*\ln(x) – 193.21$, where x = total length (mm) and y = age (d).

Similar length-age relationship equations have not been calculated for white sucker larvae. Given that the relationship curves for flannelmouth and bluehead suckers are nearly parallel (indicating similar growth rates) and that white sucker and bluehead sucker larvae hatch at more similar sizes (Snyder and Muth 2004), we applied the bluehead sucker relationship curve to white suckers as well. The data set used to generate relationship equations only included larvae ≤22 mm TL; thus, application of the relationship equations to larger fish is not advised.

For each catostomid larva captured, we inserted its TL into the appropriate relationship equation to calculate approximate age. However, we observed higher flow and lower temperature reproductive seasons than average in the Big Sandy River during this study. During the month of June, for example, mean daily water temperatures in the Big Sandy River in 2009 and 2010 were, on average, 5 and 3°C lower than Browns Park in 2004. Therefore, we added one week to the resultant age from the length-age relationship equations to account for slower growth and determined mean daily water temperature the larva experienced since hatching.

The mean daily temperature experienced by each larva was then inserted into a species-specific, temperature-dependent growth rate equation (Robinson and Childs 2001):

(8) bluehead sucker: $G = -0.210 + 0.026T$

and

(9) flannelmouth sucker: $G = -0.604 + 0.056T$, where G = growth rate (mm/d) and T = temperature (°C).

The bluehead sucker growth rate equation was also applied to white suckers.

A minimum G value of 0.125 mm/d was used when low mean temperatures produced extremely low or negative growth rates and unreasonable lengths of time since hatching (many months to over a year). In laboratory experiments, 7-d-old flannelmouth suckers were shown to grow approximately 0.125 mm/d over 28 d at 10°C (Clarkson and Childs 2000), while the above growth rate equations only predict that rate at temperatures of 12.9 and 13.1°C for bluehead and flannelmouth suckers, respectively. In the same study, however, 7-d-old flannelmouth suckers grew about 0.21 mm/d over 28 d at 14°C, which is similar to the value of 0.18 mm/d predicted by the growth rate equation. Thus, the growth rate equations may fit poorly at lower temperatures, and we applied the minimum growth rate (0.125 mm/d) when mean water temperature (from approximate hatch date to capture) was lower than 12.9°C for bluehead and white sucker larvae or 13.1°C for flannelmouth sucker larvae.

Finally, the following equation was solved to more accurately estimate number of days elapsed since each larva hatched, assuming hatch lengths of 11, 10, and 9 mm TL for flannelmouth, bluehead, and white suckers, respectively (Snyder and Muth 2004):

(10) $d = (TL_C - TL_H)/G$, where d = days since hatch, TL_C = capture length, TL_H = assumed hatch length, and G = growth rate.

The resulting number of days was subtracted from the larva's capture date to estimate a hatching date. Incubation times were extrapolated from those observed for flannelmouth suckers in laboratory experiments at 12, 16, and 20°C (Haines 1995). We used linear regression to fit a polynomial curve to observations of "time to peak hatch" (Figure 6):

(11) $y = (4.125x^2 - 163.5x + 1764)/24$, where x = temperature (°C) and y = time to peak hatch (d).

A mean value of 14 d for incubation (range: 30–6 d at 8–20°C, respectively, using equation 11) was subtracted from each larva's hatch date to obtain estimated spawning date. Corresponding discharge and water temperature on that date characterized the conditions under which each larva was spawned.

Discharge measurements were obtained from USGS gauge 09213500, immediately upstream of Big Sandy Reservoir. Water temperatures during 2009 and 2010 were recorded at hourly intervals using a TidbiT v2 temperature logger (Onset Computer Corporation) deployed approximately 30 km upstream of the gauging station at Big Sandy Reservoir (T2, Figure 3). In 2009, temperature logging began at site T1 (4 km upstream of Big Sandy reservoir) on 2 May, but that logger continually malfunctioned and was ultimately stolen. Temperature logging at T2 commenced on 23 May as roads dried, which allowed access to the installation site. In 2010, site T2 was used for comparison with 2009 and logging commenced 16 June (again, as accessed allowed). Since that is late in the reproductive season of catostomids, we used mean daily air temperatures recorded at Wyoming Department of Environmental

Quality's Juel Spring station (located approximately 10 km SW of T2) to predict mean daily water temperatures in 2010. We calculated an exponential relationship between known air and water temperatures from 16 June–30 July:

(12) $y = 6.8073e^{0.0491x}$ ($R^2 = 0.6642$), where x = air temperature (°C) and y = predicted water temperature (°C).

Predicted water temperatures were unbiased (mean difference of predicted vs. actual temperatures for dates with actual readings was essentially zero).

Drift simulations

In order to estimate rates of larval drift at flows other than those experienced by larvae during this study, we simulated downstream transport rates of drifting larvae by releasing beads into the river at various discharge levels. The semi-buoyant, gelatinous, biodegradable beads were manufactured by Key Essentials, Inc., donated to the Larval Fish Laboratory by New Mexico Interstate Stream Commission, and stored in preservative fluid in 19-L buckets.

We measured bead drift rates at several discharge levels, although targeting specific flows was not possible during the erratic period of snowmelt runoff. Simulations were conducted at sites on each side of the slight gradient change: one lower-gradient site just upstream of Big Sandy Reservoir near drift station BS1 and one higher-gradient site near Buckskin Crossing (Figure 3). For each simulation, one to three drift nets with flow meters were set downstream of the bead release location (5.0 km downstream at the low-gradient site and 6.4 km downstream at the high-gradient site, as measured using Google Earth distance tool). A 200-ml subsample of beads was removed from a bucket and counted. That value was used to extrapolate the total number of beads released in a known volume. Estimated numbers of beads released per trial ranged from 51,000–173,000 in 7.0–16.0 L, respectively. When flows allowed, beads were released across the entire width of the river channel; otherwise, beads were distributed as far across the channel as possible in the absence of being able to wade the channel during high flows. Time and water temperature were recorded for each release.

Drift net samples were collected and processed every 10 to 20 minutes until the first beads were detected. Sampling continued after first detection of beads to determine the peak and end of bead drift; however, nets were set less frequently as bead capture rates declined. Time elapsed since release, flow meter readings, and numbers of beads captured were recorded for each sample. Collections ceased when bead captures declined considerably (approximately five or less per sample).

Minimum, maximum, and mean discharge levels during each trial were obtained from USGS gauge 09213500. Trial discharges were grouped into 100-cfs categories and converted to metric units for analysis (Table 1). Water velocities and volumes sampled were calculated from flow meter readings (Formulas 1 and 2, above) and some velocities were verified with readings taken in the field using a Marsh McBirney FloMate 2000 flow meter. Finally, we calculated rates of bead drift (m/s): distances travelled by beads divided by the time to travel those distances.

Seine sampling

We commenced seine sampling for larval and juvenile catostomids when larval drift sample sizes and, therefore, processing times were considerably reduced. Seining locations were chosen based on established access; thus, most were near drift net stations or drift simulation trial sites. Additional seining was conducted in Sculpin Creek and in higher-gradient upstream reaches. Custom seines were manufactured by Nylon Net Co. and measured 3.0 m x 1.2 m x 0.16 cm. Seining was usually performed in a downstream direction in current and from the mouth to the head of a backwater. Riffles were "kick-seined": a seine was held stationary at the downstream end of a riffle by one person, while another person vigorously disturbed gravel and cobble substrate and dislodged fish upstream of the seine.

For each seine location and occasion, we recorded a physical site description, UTM coordinates (WGS 84), start time, water temperature (°C, by handheld thermometer), and mean daily discharge at USGS gauging station 09213500 (m^3/s). We sampled a variety of low-velocity habitats including: backwaters, side channels, main channel shorelines, scour pools, and undercut banks. For each seine haul, we recorded habitat type; length (m), width (m), and mean depth (cm); fish capture, preservation, and/or release. Fish identified to species in the field were counted, measured for minimum and maximum TLs (nearest 1.0 mm), and released if native or removed if non-native. Those unidentifiable in the field were preserved in 100% EtOH or 10% formalin for later identification, then verified, counted, measured, cataloged, and stored at the Larval Fish Laboratory, Fort Collins, Colorado. Seine haul areas and fish counts from each location and occasion were combined to calculate fish densities.

RESULTS

Larval drift sampling, 2009

The most downstream drift net station, BS1, was sampled on 23 occasions from 16 June to 7 August 2009 (15 morning sets, eight evening sets). Either two or three drift nets were set per occasion, depending on discharge. The middle station, BS2, was sampled on eight occasions from 1 July to 6 August 2009 (three morning sets, five evening sets). Impassable, muddy roads impeded earlier access to that site. The most upstream station at the confluence with Sculpin Creek, BS3, was sampled on eight occasions from 25 June to 5 August 2009 (four morning sets, four evening sets). Three drift nets were set on each occasion at both the middle and upstream stations. Each net was set for an average of 60 minutes (range: 43–67 minutes). Mean discharge during net-sets ranged from 15.9 m^3/s on 25 June 2009 to 1.4 m^3/s on 5 August 2009. Higher discharge peaks (Figure 7) were not sampled due to safety and efficiency. Mean discharge during sampling at BS1 was higher than at other stations (Table 2), however sampling commenced one to two weeks earlier there. Percent of total river volume sampled by drift nets per occasion ranged from about 1.3% during high discharge in late June to 17.8% in early August (Figure 8). Water temperatures (taken by handheld thermometer) averaged 12.5°C (range: 9–16°C) during morning net-sets and 18.9°C (range: 12–22°C) during evening net-sets.

Flannelmouth sucker was the most abundant species captured (56%, Table 3), followed by white sucker (24%) and bluehead sucker (14%), when samples from all three stations were combined. Mean total lengths at capture were 15.7 mm (range: 12.0–30.0 mm) for flannelmouth sucker, 14.2 mm (range: 12.0–24.0 mm) for bluehead sucker, and 13.9 mm (range: 11.5–45.5 mm) for white suckers (Figure 9). Remaining captures included questionable identity (less morphologically and/or meristically definitive) specimens of the three sucker species, hybrid sucker combinations, a possible longnose sucker, unidentifiable (damaged) suckers, mottled sculpin, lake chub, and embryos (mostly catostomids, based on size > about 2.8 mm diameter). Remaining results refer solely to definitively-identified specimens of the three catostomid species.

Most catostomid larvae were captured at station BS1 (*n* = 817) in 2009, and their abundance declined upstream at BS2 (*n* = 235) and BS3 (*n* = 60). Although more sampling occurred at BS1, mean catch per hour was also higher at that station (13.4 larvae/hour) than at BS2 (9.6 larvae/hour) or BS3 (2.5 larvae/hour, Table 4). Number of larvae captured per volume of water sampled followed a similar pattern (Table 4). Flannelmouth sucker was the most abundant catostomid species collected at station BS1 (73%, Table 5), while bluehead sucker made up the largest portion at BS2 (41%). White and bluehead sucker were captured in similar proportions at BS3 (42 and 37%, respectively), while flannelmouth sucker made up only 22% of catostomids at that station. Abundance of all sucker species at BS3 was low.

At downstream station BS1, flannelmouth suckers were captured on 12 of 23 sampling occasions from 16 June –5 August 2009 (Figure 10), and captures on 1 July (*n* = 321) accounted for 48% of all flannelmouth sucker drift net captures that year. Bluehead suckers were captured at BS1 on 9 occasions from 2 July–6 August, and white suckers were captured on 13 occasions from 16 June–23 July. At station BS2, bluehead suckers were captured on three of eight occasions from 6–16 July (Figure 11), and captures on 8 July (*n* = 88) made up 54% of all bluehead sucker captures. Flannelmouth suckers were captured there on four occasions from 1–16 July and white suckers were captured on five occasions from 6 July–3 August. At BS3, we captured bluehead suckers on six of eight occasions from 9 July–5 August, white suckers on four occasions from 14 July–5 August, and flannelmouth suckers on three occasions from 9 July–5 August (Figure 12).

Maximum densities of catostomids (numbers per volume of water sampled) collected by drift nets in 2009 were 252 flannelmouth suckers/1000 m^3, 83 bluehead suckers/1000 m^3, and 60 white suckers/1000 m^3 (Figure 13). Densities of bluehead sucker were extremely low overall (11/1000 m^3 or less), with the exception of the maximum density noted above. Mean densities were lowest for all three species at station BS3. Mean densities were highest for flannelmouth suckers at station BS1, and for bluehead suckers and white suckers at BS2.

Estimated numbers of flannelmouth suckers that drifted past station BS1 per 24 hours on sampling days in 2009 ranged from 0 to 238,617 (Figure 14) and totaled 482,065. Numbers of bluehead suckers ranged from 0 to 6,852 and totaled 26,517. Numbers of white suckers ranged from 0 to 26,472 and totaled 93,592. Using interpolation for values when no sampling occurred, we estimated that nearly 1,350,000 flannelmouth suckers, 52,000 bluehead suckers, and 188,000 white suckers may have drifted downstream past station BS1 and into Big Sandy Reservoir from 16 June through 7 August 2009. Our estimates employed interpolation for days not sampled only within short periods of consistent captures of each species: 13 d within a 23-d period for flannelmouth suckers, 7 d within a 13-d period for bluehead suckers, and 12 d within a 21-d period for white suckers. The entire sampling season spanned 53 d.

Larval drift sampling, 2010

The most downstream drift net station, BS1, was sampled on 35 occasions from 8 June to 30 July 2010 (19 morning sets, 16 evening sets). Net-sets occurred during both morning and evening on 8, 9, 17 and 30 June, as well as 21 July. One to three drift nets were set per occasion, depending on discharge. Impassable, muddy roads impeded earlier access to stations BS2 and BS3. The middle station, BS2, was sampled on 11 occasions from 22 June to 29 July 2010 (eight morning sets, three evening sets). Two to three drift nets were set, depending on discharge. The most upstream station at the confluence with Sculpin Creek, BS3, was sampled on eight occasions from 22 June to 28 July 2010 (two morning sets, six evening sets). Three drift nets were set on each occasion. Each net was set for an average of 60 minutes (range: 31–68 minutes). Mean discharge during net-sets ranged from 17.7 m^3/s on 08 June 2010 to 1.3 m^3/s on 30 July 2010. Higher discharge peaks (Figure 7) were not sampled due to safety and efficiency. Mean discharge during sampling at BS1 was higher than at other stations (Table 2), however sampling commenced two weeks earlier there. Percent of total river volume sampled by drift nets per occasion ranged from about 0.4% during high discharge in late June to 24.9% in late July (Figure 8). Water temperatures (taken by handheld thermometer) averaged 11.8°C (range: 7–16°C) during morning net-sets and 17.3°C (range: 9–23°C) during evening net-sets.

White sucker was the most abundant species captured (47%, Table 3), followed by flannelmouth sucker (35%) and bluehead sucker (7%), when 2010 samples from all three stations were combined. Mean total lengths at capture were 15.6 mm (range: 12.0–18.5 mm) for flannelmouth sucker, 15.4 mm (range: 12.0–52.0 mm) for bluehead sucker, and 13.5 mm (range: 11.0–17.0 mm) for white sucker (Figure 15). Remaining captures included questionable identity (less morphologically and/or meristically definitive) specimens of the three sucker species, hybrid sucker combinations, possible longnose suckers, unidentifiable (damaged) suckers and other specimens, mountain whitefish, speckled dace, fathead minnow, and embryos (mostly catostomid, based on large size). Remaining results refer solely to definitively-identified specimens of the three catostomid species.

Most catostomid larvae were captured at station BS1 (n = 343) in 2010, but more sampling occurred there. Catch per hour, however, was slightly higher at station BS3 (4.7 larvae/hour) than at other stations (Table 6), and all were generally lower than in 2009. Numbers of larvae captured per volume of water sampled were similar among stations (Table 6). White sucker was the most abundant catostomid species collected at stations BS1 and BS2 (60% and 46%, respectively; Table 7), followed by flannelmouth and bluehead sucker, in descending order. Flannelmouth sucker made up the largest portion at BS3 (45%), followed by white and bluehead sucker.

At downstream station BS1, flannelmouth suckers were captured on 12 of 35 sampling occasions from 25 June –16 July 2010 (Figure 16). Captures on 30 June and 1 July (n = 102) accounted for 51% of all flannelmouth sucker drift net captures and those on 30 June consisted of two occasions: one morning and one evening net-set. Bluehead suckers were captured at BS1 on six occasions from 17 June–16 July, and white suckers were captured on ten occasions from 28 June–14 July. At station BS2, flannelmouth suckers were captured on four of eleven occasions from 29 June–14 July (Figure 17).

Bluehead suckers were captured there on five occasions from 23 June–14 July and white suckers were captured on six occasions from 6 July–23 July. At BS3, flannelmouth suckers were captured on four of eight occasions from 6–15 July, bluehead suckers on four occasions from 13–28 July, and white suckers on five occasions from 6–20 July (Figure 18).

Maximum densities of catostomids (numbers per volume of water sampled) collected by drift nets in 2010 were 49 flannelmouth suckers/1000 m^3, 6 bluehead suckers/1000 m^3, and 61 white suckers/1000 m^3 (Figure 19). Mean densities of flannelmouth and bluehead sucker did not vary much by station: 2–4/1000 m^3 and <1–2/1000 m^3, respectively. Mean densities of white suckers were 7, 3, and 3/1000 m^3 at stations BS1, BS2, and BS3, respectively.

Estimated numbers of flannelmouth suckers that drifted past station BS1 per 24 hours on sampling days in 2010 ranged from 0 to 40,218 (Figure 20) and totaled 65,926. Numbers of bluehead suckers ranged from 0 to 1,946 and totaled 5,601. Numbers of white suckers ranged from 0 to 22,924 and totaled 93,958. Using interpolation for values when no sampling occurred, we estimated that approximately 147,000 flannelmouth suckers, 10,000 bluehead suckers, and 170,000 white suckers may have drifted downstream past station BS1 and into Big Sandy Reservoir from 8 June through 30 July 2010. Our estimates employed interpolation only within short periods of consistent captures of each species: 10 d of a 20-d period for flannelmouth suckers, 4 d of a 7-d period for bluehead suckers, and 8 d of a 17-d period for white suckers. The entire sampling season spanned 53 d.

Spawning season, 2009

We estimated 2009 peak spawning period for flannelmouth sucker to be 30 April–18 May (range: 22 April–21 June, Figure 21). Approximately 85% of captured larvae were estimated to have been spawned during that 19-d peak period. Nearly 76% of bluehead sucker larvae were spawned during a 20-d period from 15 May–3 June (range: 5 May–13 July, Figure 22). Approximately 83% of captured white sucker larvae were estimated to have been spawned during a 28-d period from 13 May–9 June, Figure 23). Estimated lengths of entire white sucker spawning periods were 11 and 20 d longer than those of bluehead and flannelmouth suckers, respectively. Flannelmouth sucker larvae were captured on the first sampling occasion (16 June, n = 2), so spawning may have commenced for that species earlier than the beginning date in our estimated range. White sucker was also captured on the first occasion (n = 1, 46 mm TL), but that individual was produced in 2008 and not included in spawning date calculations.

Mean daily discharge throughout the entire spawning periods of all three catostomids ranged from 1.4–20.2 m^3/s. Peak flannelmouth sucker spawning may have occurred prior to spring snowmelt runoff (Figure 21) and mean daily discharge during that time averaged 2.0 m^3/s. The majority of bluehead sucker spawning coincided with the initial spike in discharge during spring runoff (Figure 22) and mean daily discharge averaged 11.5 m^3/s during estimated peak spawning. Mean daily discharge averaged 10.8 m^3/s during peak white sucker spawning.

Mean daily water temperatures at temperature logger site T2 (Figure 3) were available in 2009 starting 23 May. For 12 d of the 20-d bluehead sucker *peak* spawning period when temperatures were available, daily water temperatures averaged 9.2°C (range: 7.4–11.0°C, Figure 24).

Spawning season, 2010

We estimated 2010 peak spawning period for flannelmouth sucker to be 3 May–20 May (range: 30 April–25 June, Figure 25). Approximately 67% of captured larvae were estimated to have been spawned during that 18-d peak period. Approximately 68% of bluehead sucker larvae were spawned during a 24-d period from 16 May–8 June (range: 10 May–4 July, Figure 26). Approximately 84% of white sucker larvae were spawned during a 27-d period from 9 May–4 June (range: 3 May–20 June, Figure 27). No catostomid larvae were captured during the first several weeks of sampling, so we have confidence in our estimates of spawning commencement. The first bluehead suckers to appear in 2010 drift samples (n = 2, 35 and 52 mm TL) were produced in 2009, captured on 17 June and 23 June, respectively, and not included in spawning date calculations.

Mean daily discharge throughout the entire spawning periods of all three catostomid species ranged from 1.2–28.9 m^3/s. Peak flannelmouth sucker spawning appeared to have occurred prior to spring snowmelt runoff (Figure 25) and mean daily discharge during that time averaged 1.6 m^3/s. The peak of bluehead sucker spawning coincided with the ascending limb of the hydrograph (Figure 26) and mean daily discharge averaged 5.3 m^3/s. Peak white sucker spawning seemed to occur prior to peak spring runoff (Figure 27) and mean daily discharge averaged 3.0 m^3/s.

Mean predicted daily water temperatures (equation 12 in Methods) at temperature logger site T2 during peak spawning periods averaged 8.6°C (range: 5.9–12.7°C) for flannelmouth sucker, 11.0°C (range: 7.7–15.5°C) for bluehead sucker, and 9.9°C (6.9–13.9°C) for white sucker.

Drift simulations

We conducted eight drift simulation trials at each of the low- and high- gradient sites. Mean discharge during trials ranged from 2.5–13.1 m^3/s at the low-gradient site and 2.5–13.6 m^3/s at the high gradient site (Table 8). Mean water velocities (calculated from flow meters at net mouths) at each discharge level ranged from 0.50–0.81 m/s during low-gradient trials and 0.40–0.90 m/s during high-gradient trials (Table 9). Percents of total river volume sampled by each net were lower during trials at high discharge levels and increased as flows dropped, as expected. During the highest-discharge trials, we sampled approximately 1% of total river volume per net at both low- and high-gradient sites. During the lowest-discharge trials, each net sampled an average of 3% and 2% of total river volume at low- and high-gradient sites, respectively. Percent of beads captured per trial was low at both sites (<0.1–3.6%), but was higher at the low-gradient site for most discharge levels (Table 10). Ratios of percents of river volume sampled per trial (all nets) to percents of beads captured followed no discernible pattern at the low-gradient site (range: 2:1–49:1). The noticeably large ratio (49:1) for the one low-gradient trial at an intermediate discharge level was the result of an inexplicably low bead capture. At the high-gradient site, ratios of volumes sampled to beads captured were extremely high at the lowest discharge levels and decreased considerably as discharge levels increased (68:1 down to 3:1). If beads were uniformly distributed throughout the river channel and drifted at the same rate as water flowed, ratios would be 1:1.

Times elapsed to first capture, peak capture, and last capture of beads were generally similar between low- and high-gradient trials at higher discharge levels (Table 11). During one trial at the lowest discharge level (0–2.8 m^3/s), no beads were captured at the high-gradient site after nearly eight hours of sampling. In another trial at that discharge level, beads took more time to arrive at the high-gradient capture site than during a similar low-discharge trial at the low-gradient site.. Mean velocities of beads captured were higher during high-gradient trials than low-gradient trials (Table 12).

Seine sampling, 2009

We conducted seine sampling on five occasions near downstream drift net station BS1 and on three occasions each near stations BS2 and BS3 from 5 August–17 October. Sculpin Creek was sampled on three occasions (25 June, 25 August, and 17 October) and an area downstream of Buckskin Crossing was sampled on one occasion (25 August). One to nine seine haul samples were taken at each location per occasion. Mean daily discharge of Big Sandy River from 5 August–26 August ranged from 1.3–0.8 m^3/s (Figure 7). No discharge measurements were available for Big Sandy River on 17 October (after the gauging station ceased operation), but discharge levels had dropped to 0.3 m^3/s by the last week of September and October stream flow levels were presumably at or below those levels. No discharge measurements were available for the generally low-flow Sculpin Creek. Water temperatures ranged from 12–21°C during early-August sampling, 12–22°C during late-August sampling, and 3–9°C during October sampling.

We completed 67 seine hauls at all locations combined, with a mean area of 24.1 m^2 (range: 1.5–67.4 m^2). Backwaters were the most frequently sampled habitats (n = 15), followed by main channel shoreline (n = 14) and side channels (n = 13, Table 13). Most seine hauls and greatest area seined were located near site BS1, followed by BS2 and BS3 (Table 14). Of 67 seine hauls, 53 (79%) captured fish. Of 2,451 total fish captured, 34% were white suckers, 27% were lake chub, 20% were bluehead suckers, and 15% were flannelmouth suckers (Table 15). Remaining 4% of captures included questionable identity (less morphologically and/or meristically definitive) specimens of the three sucker species, hybrid sucker combinations, longnose sucker, mountain sucker, mottled sculpin, as well as native and non-native cyprinid and salmonid species. Remaining results refer solely to definitively-identified specimens of the three sucker species.

White sucker was captured in higher proportions than native catostomid species at all sampling locations and was the only catostomid captured at Buckskin Crossing (Table 16). Bluehead suckers outnumbered flannelmouth suckers at sites BS2 (33% vs. 22%) and BS3 (39% vs. 7%), while flannelmouth suckers outnumbered bluehead suckers at BS1 (39% vs. 15%). Very few native catostomids were captured in Sculpin Creek. Minimum and maximum TL of bluehead and flannelmouth suckers captured by seine increased on each sampling occasion, but the widest range of TLs of white suckers was found during August sampling (Figure 28). White suckers captured during June in Sculpin Creek measured 32–42 mm TL and were certainly produced in 2008.

Densities of catostomids in seine haul samples varied by season and location. Among mainstem locations in 2009, mean densities of each species were higher in August samples than October samples (Figure 29). In August samples at those locations, mean densities of all species were highest at BS2. The low number of sampling occasions per location and season (n = 1–4) precluded statistical comparison. We found a particularly high density of white suckers in Sculpin Creek during August sampling: 3.3/m^2. Bluehead and flannelmouth sucker densities in Sculpin Creek ranged from 0–0.7/m^2 across all seasons.

Seine sampling, 2010

We expanded our seine sampling from five locations in 2009 (BS1, BS2, BS3, Sculpin Creek, and Buckskin Crossing) to seven locations in 2010 (Big Sandy Reservoir, downstream of gauging station, BS1, BS2, BS3, Sculpin Creek, and WGFD reach 21). Samples in Big Sandy Reservoir and downstream of the gauging station were added in 2010 to determine if native catostomids did, in fact, survive in the reservoir and would be affected by a barrier to upstream movement from there. Reach 21 was a 2.4-km stretch of Big Sandy River (around RK 63.3) sampled by WGFD with electrofishing for non-native species removal in 2009. It was chosen out of 30 reaches because both flannelmouth and bluehead sucker were present during removal efforts and, ultimately, because we were able to access it. We sampled the shoreline and inlet of Big Sandy Reservoir on six occasions from 14 July–12 August. Several locations within 3.5 km downstream of the gauging station were sampled over four occasions from 7 July–11 October. The October sample consisted on one seine haul pulled immediately downstream of a concrete diversion structure at the gauging station and captured >1000 YOY catostomids, which were not enumerated. We sampled near downstream drift net station BS1 on four occasions from 22 July–11 October, near station BS2 on three occasions from 29 July–11 October, near station BS3 on three occasions from 28 July–12 October. Sculpin Creek and a location within WGFD reach 21 were each sampled on two occasions (11 August and 12 October). One to twelve seine haul samples were taken at each location per occasion. Mean daily discharge of Big Sandy River from 7 July–12 October ranged from 5.1–0.2 m^3/s (Figure 7). Water temperatures ranged from 14–22°C during July sampling, 15–23°C during August sampling, and 6–14°C during October sampling.

We completed 112 seine hauls at all locations combined, with a mean area of 22.3 m^2 (range: 2.0–92.4 m^2). Shorelines were the most frequently sampled habitats (n = 40), followed by backwaters (n = 20) and eddies (n = 15, Table 17). More seine hauls were located near site BS1 than other sites and greatest area seined was in Big Sandy Reservoir (Table 18). Of 112 seine hauls, 90 (80%) captured fish. Of 7,761 total fish captured, 53% were white suckers, 20% were bluehead suckers, 9% were lake chub, 4% were fathead minnows, and 4% were flannelmouth suckers (Table 19). The remaining 10% of captures included mountain sucker, longnose sucker, questionable identity (less morphologically and/or meristically definitive) specimens of all sucker species, hybrid sucker combinations, mottled sculpin, as well as native and non-native cyprinid and salmonid species. Remaining results refer solely to definitively-identified specimens of the three catostomid species.

Upstream of the gauging station, white sucker was captured in higher proportions than native catostomid species at all sampling locations except BS3, near Sculpin Creek (Table 20). Bluehead sucker made up the smallest proportions at most locations, except WGFD reach 21 (42% of catostomids) and BS3 (90% of catostomids). Flannelmouth sucker was captured in the lowest proportion overall: 8% of catostomids (range: 4–24% per location). Of the three catostomid species, white sucker was the only one captured in Big Sandy Reservoir and accounted for 83% of catostomids captured in the stretch downstream of the gauging station. Also in samples from that stretch were 59 flannelmouth suckers (more than at some locations upstream, Table 19), plus an additional 55 or more from the one seine haul pulled in October immediately downstream of the gauging station diversion structure. Minimum and maximum TL of bluehead, flannelmouth, and white suckers captured by seine at all locations increased between July/August sampling and October sampling (Figure 30). White suckers captured during July in Big Sandy Reservoir measured up to 126 mm TL, which were certainly age-1 fish.

Densities of catostomids in 2010 seine haul samples from locations upstream of the gauging station (BS1–3, reach 21, and Sculpin Creek) varied by species, season, and location. Mean densities of bluehead sucker ranged from 1.6–7.7/m^2 at BS3 and were <1.0/m^2 at all other locations. The highest bluehead sucker density at BS3 was observed in August, while seasonal patterns at other locations varied. Flannelmouth sucker mean densities at those same locations were generally low across all seasons: 0–0.3/m^2, except for a higher mean density at site BS2 in July samples (3.8/m^2).
Mean density of white sucker in samples from BS2 in July was also high: 9.2/m^2. We found a particularly high density of white suckers in the seine haul immediately downstream of the gauging station diversion structure during October sampling: >1000 in an area approximately 45 m^2. White sucker densities in reservoir samples ranged from 0.1–32.5/m^2 (mean: 7.1/m^2). The low number of sampling occasions per location and season (n = 1–5) precluded statistical comparison.

Discussion

Larval drift

Flannelmouth, bluehead, and white sucker all reproduced in Big Sandy River during 2009 and 2010, as evidenced by presence of larvae of each species in drift net collections. We captured more than twice as many catostomids in 2009 drift net sampling (n = 1112) compared to 2010 sampling (n = 509), despite more effort in 2010. Native flannelmouth and bluehead sucker made up 75% of definitively identified catostomid larvae captured in 2009 drift net samples, but only 47% of 2010 samples. We found evidence of spatial differentiation in drift of catostomid larvae in both years: flannelmouth and white suckers were captured most frequently at downstream station BS1, while bluehead suckers were captured in the highest numbers at the middle (BS2) and upstream (BS3) stations in 2009 and 2010, respectively. Higher abundance of flannelmouth sucker nearest the reservoir than at upstream stations indicated that species may be most negatively affected by a barrier. A greater proportion of flannelmouth suckers were captured at upstream station BS3 in 2010 (25%) than in 2009 (2%), possibly due to longer spawning period, lower discharge, and higher subsequent larval retention in 2010. The multiple, high peaks in 2009 discharge may have transported more larvae out of upstream reaches than the single peak in 2010. Fewer bluehead suckers were captured downstream (5% and 3% of BS1 catostomids in 2009 and 2010, respectively), suggesting the species spawns further upstream and may be less affected by a downstream barrier. Drift patterns supported the idea that catostomid drift in Big Sandy River is partitioned and occurs over a relatively small area among these species. Our results were consistent with adult movement patterns observed by Sweet (2007) during presumed peak spawning in 2007: 50% of locations of radio-tracked flannelmouth suckers were approximately between RK 40 and 12 and 50% of bluehead sucker locations were between RK 65 and 45. Most flannelmouth sucker larvae were captured during this study at station BS1 (RK 4.0), while most bluehead sucker larvae were captured at BS2 (RK 18.3) or BS3 (RK 45.2).

In each year, few hybrid combinations or non-native longnose suckers were captured, and no native mountain suckers were detected in drift samples. Longnose sucker was introduced to the system prior to 1970 (Baxter and Simon 1970), but has not spread much. In fact, the species is not listed as occurring in the Green River Basin in the more recent *Fishes of Wyoming* (Baxter and Stone 1995). However, white and longnose sucker were the most abundant species in juvenile and adult electrofishing samples from more than 90 km of Big Sandy River upstream of the reservoir in 2009 (Atwood et al. 2011); although longnose sucker captures dropped from 1,066 in 2009 to 6 in 2010. We likely did not detect much longnose sucker reproduction in either year due to the location of our drift net stations: our most-upstream station was at RK 45.2, while both Sweet (2007) and Atwood et al. (2011) found most longnose suckers upstream of RK 60. Mountain sucker was not mentioned by Sweet (2007) and varied in abundance in recent electrofishing efforts: n = 14 in 2009 and n = 74 in 2010 (Atwood et al. 2011).

Positive identification of these sympatric species and all hybrid combinations can be complicated, at best. Our capture of larval catostomid specimens of questionable identity (2–3% of catostomid captures each year; not included in analyses) along with the variation in types and abundance of hybrid combinations captured by WGFD from 2009 to 2010 (Atwood et al. 2011) warrant continued monitoring of hybridization levels among native and non-native catostomids in the Big Sandy River, including thorough training of field personnel and collection of voucher specimens for verification of field identifications.

We compared densities of drifting larvae in this study to those from drift net samples collected in the Yampa River, Colorado, during 2008 and 2009 (K. Bestgen, unpublished data; Figure 32). The Yampa River is similar to the upper Big Sandy River in that it is a virtually unregulated tributary to the Green River and supports populations of reproducing flannelmouth and bluehead suckers in the presence of several non-native species, which are currently subject to removal efforts (Bestgen et al. 2007a). Densities of drifting flannelmouth sucker larvae were similar between station BS1 in 2009 and the Yampa River in 2008. Densities of bluehead sucker larvae at station BS2 (2009) and BS3 (2010) were lower than those for both years in the Yampa River. However, sampling in this study did not occur daily as in the Yampa River. If larger peaks of drift were missed, densities and numbers of suckers transported downstream to the Big Sandy Reservoir may be underestimated. Still, Yampa River density estimates may also be conservative, given that catostomid captures were made in drift net sampling aimed at capturing Colorado pikeminnow *Ptychocheilus lucius*, which only commence spawning in summer (late June-early August) when water temperatures exceed 16–18°C (Tyus and Haines 1991; Bestgen et al. 1998).

Sampling in the Yampa River produced drift densities for both species that varied between years. Dependence of the system's stream flow on snowmelt runoff is one factor that contributes to that annual variation. The Big Sandy River undergoes similar environmental variation that affects larval drift. Spring run-off in this study was higher than average (Figure 7) and may have increased downstream drift. Conversely, for a given number of larvae in the system, increased volumes of water would decrease the estimated densities of drifting larvae. Therefore, estimating larval drift abundances and densities in the Big Sandy River during more average water years is essential to understanding how high-water conditions affected our results. However, larval abundance can also vary annually with abundance of adults and production of larvae at spawning areas, mortality of eggs or larvae, and sampling error (Bestgen et al. 1998), so care must be taken when attributing cause to observed variation.

Estimated numbers of native catostomids that drifted past downstream station BS1 and, presumably, into Big Sandy Reservoir were higher in 2009 than 2010 and higher for flannelmouth sucker than bluehead sucker. For the drift net sampling periods lasting 7.5 weeks each year, we estimated about 1,350,000 flannelmouth suckers and 52,000 bluehead suckers drifted past BS1 in 2009 and 147,000 flannelmouth suckers and 10,000 bluehead suckers in 2010. Our estimates assumed that (1) drift was constant over a 24-hour period and (2) larvae were distributed evenly. We found the first assumption reasonable, given that we did not sample during suggested times of highest or lowest drift. Even distribution of larvae throughout the water column was supported by Carter et al. (1986), although they found higher concentrations in shoreline samples of the much wider channel of the Colorado River. Uneven distribution would result in either over- or underestimation of numbers drifting past shoreline station BS1. We should expect more even distribution across the channel of Big Sandy River, particularly at drift net locations where the channel width measured approximately 10–20 m, depending on discharge. Our estimates employed interpolation for days not sampled only within short periods of consistent captures (no intervening sampling days with zero captures) of each species. Duration of drift was relatively short for both species and peak captures of flannelmouth sucker, in particular, were large but fleeting at BS1 in both years. Although there were likely larvae of one or all species drifting past station BS1 on days between sampling days when none were captured, we had no way of calculating those numbers and retained the more conservative strategy. Our estimates of native catostomid larvae that drifted past station BS1, although conservative, may be higher than what would be lost to the reservoir in an average water year.

Using regression equations developed for fecundity of flannelmouth suckers (McAda and Wydoski 1985) and bluehead suckers (McAda and Wydoski 1983) in the Green and Yampa rivers, along with TLs of those species captured during WGFD non-native removal efforts in the Big Sandy River (Atwood et al. 2011), we calculated the approximate numbers of adult females required to produce the larvae estimated to have drifted past station BS1. A 457-mm-TL flannelmouth sucker female (mode of WGFD data) may produce about 10,450 ova, so 130 of those females would be required to produce the 1,350,000 larvae that drifted past BS1 in 2009 (assuming no mortality of embryos or larvae). As few as 15 females may have generated the 147,000 flannelmouth sucker larvae that drifted past BS1 in 2010. A 381-mm-TL bluehead sucker female (mode of WGFD data) may produce about 7,600 ova, so only 7 and 2 of those females in 2009 and 2010, respectively, may have been required to produce the bluehead sucker larvae that drifted past station BS1. The number of catostomid females needed to produce the estimated numbers of larvae may actually be higher in the Big Sandy River if colder water temperatures reduced fecundity. Actual numbers and lengths of adult suckers in the system, if available, could be used to estimate potential reproduction in the Big Sandy River and, thereby, allow an estimate of production lost to Big Sandy Reservoir.

Spawning season

Spawning seasons for flannelmouth and bluehead suckers in the Upper Colorado River Basin have been described generally as “April to May” (Chart and Bergersen 1992), “May to June” (McAda and

Wydoski 1985; Bezzerides and Bestgen 2002), or "spring to early summer" (Bezzerides and Bestgen 2002). Estimated peak spawning periods in the Big Sandy River were remarkably similar between 2009 and 2010 for each species: 30 Apr–18 May 2009 and 3 May–20 May 2010 for flannelmouth sucker and 15 May–3 June 2009 and 16 May–8 June 2010 for bluehead sucker. Our spawning period calculations and species' distributions among our drift net samples correlated with the spatial segregation and presumed spawning movements observed by Sweet (2007) via radio telemetry, described above.

In both 2009 and 2010, most flannelmouth and white sucker spawning in the Big Sandy River may have occurred prior to snowmelt runoff, while bluehead sucker spawning appeared to increase as flows increased. The timing of captures among years (toward the end of peak runoff in 2009 and well after the peak in 2010, Figures 21–23 and 25–27) along with the timing of most captures at each station (earlier at downstream BS1 and later at upstream BS3, Figures 10–12 and 16–18), illustrated that thermal characteristics may be more important as spawning cues than discharge levels. Mean water temperature during the bluehead sucker peak spawning period was 9.2°C or lower in 2009 and was likely similar for the flannelmouth sucker peak period estimated to have begun 11 d earlier, although temperature data was unavailable prior to 23 May. We estimated mean water temperatures during 2010 flannelmouth and bluehead sucker peak spawning periods to be 8.6°C and 11.0°C, respectively. Mean temperatures for the above peak spawning date ranges in 2005 and 2006, respectively, were 9.9 and 10.9°C for flannelmouth sucker and 10.7 and 11.8°C for bluehead sucker (K. Gelwicks, WGFD, unpublished data).

The complex methods we employed to back-calculate spawning periods were dependent on several uncertain variables, due to the lack of well-documented, species-specific incubation times and growth rates at the low temperatures observed in the Big Sandy River during spring. Our spawning-period estimates provide valuable information about the species' reproduction in the northern portions of their ranges, but would be enhanced with incubation rate data from fish cultured at lower temperatures.

Drift simulations

We conducted drift simulation trials, using semi-buoyant gelatinous beads, in order to estimate rates of larval drift at flows other than those expected during the 2009 reproductive season. Near neutrally-buoyant beads have been widely employed as surrogates for drifting fish larvae (Childs et al. 1998; Reinert et al. 2004; Hedrick et al. 2009) and allow researchers to conduct drift-related investigations without capturing live animals.

We performed trials at a site in each of the low- and high-gradient portions of the Big Sandy River, but did not identify many consistent patterns. Our trial results showed that drift-net sampling efficiency for beads may not correlate well with volumes of water sampled, regardless of gradient or discharge level: percents of river volume sampled were often many times higher than percents of beads captured from known numbers released (Table 10). If beads were uniformly distributed throughout the river channel and drifted at the same rate as water flowed, ratios of volumes sampled to beads captured would be 1:1. However, bead buoyancy varies with water temperature due to the gelatinous nature of the product. We did observe some beads dropping out of the current and rolling along the river bottom on all occasions, resulting in reduced bead captures compared to volumes of water sampled.

Furthermore, water velocities measured during trials were 1.1–2.3 times faster than velocities of beads captured (Table 12). Bluehead and flannelmouth sucker larvae have the ability to actively disperse and are not completely at the mercy of currents and river morphology (Robinson et al. 1998), and they may seek refuge from current in the same quiet, near-shore habitat in which beads were deposited. Therefore, ratios of river volume sampled to larvae captured would also be higher than 1:1, resulting in overestimation of numbers of native catostomids drifting past station BS1 and into Big Sandy Reservoir (which used percent of river volume sampled as a surrogate for percent of fish sampled).

Mean bead velocities were higher during high-gradient trails than low-gradient trials at most discharge levels, as expected, but few or no beads reached the high-gradient drift nets during the lowest discharge trials. The extreme sinuosity of the upper half of the study area impeded progress of beads even at high discharge levels, and transport rates at the lowest flows there were negligible. Consequently, percent of beads captured increased as discharge levels increased at the high-gradient site, even though we were sampling smaller proportions of total river volume. If larvae drift similarly to beads, that sinuosity may aid in retention of sucker larvae spawned in upstream reaches and explain the low incidence of bluehead suckers, in particular, at downstream drift station BS1 even at the highest flows sampled.

Ultimately, drift simulations using semi-buoyant beads as surrogates for drifting catostomid larvae may have limited use in systems like the Big Sandy River. Appropriate comparisons to validate beads as surrogates for larvae would need to include simultaneous releases of beads as well as marked larvae in order to demonstrate similarities or differences. Hedrick et al. (2009) demonstrated the validity of beads as surrogates in the Green River, Utah, but trials were conducted in an unbraided, non-sinuous portion of the river. The physical nature of the Big Sandy River complicated estimation of our sampling efficiency, but drift simulation trials provided valuable insight into how catostomid larvae may behave in the system.

Seine sampling

Very little sampling for young-of-the-year (YOY) catostomids had been conducted in the Big Sandy River prior to this study, but incidental catch from other studies provided useful information. Sampling by WGFD during a native fish survey in 2003 found higher frequencies of YOY native suckers than white suckers: of 272 catostomids <60 mm TL, 87% were flannelmouth suckers, while 4% and 2% were bluehead and white suckers, respectively (Sweet 2007); however, location, gear, and effort were not described. In 2006, Sweet (2007) only captured 291 catostomids <51 mm TL (unidentified) in combined hoop net, backpack electrofishing, and seine sampling. The studies may not have been targeting YOY fish, but the latter certainly employed gear capable of capturing that life stage and noted the paucity of YOY suckers (as well as later year classes) of all species. In contrast, our targeted (but not comprehensive) seine sampling to investigate retention of YOY catostomids produced approximately 1,300 suckers ≤60 mm TL in 2009 and over 2,200 in 2010.

Highest young-of-the-year (YOY) catostomid densities among mainstem locations upstream of the gauging station were found in seine samples collected near stations BS2 and BS3. While sampling, we noted more channel complexity at BS2, in particular, than at other locations. We often captured more and higher densities of white suckers than native suckers, except at BS3 in 2010 where bluehead suckers outnumbered other catostomids. Densities of all species at mainstem locations upstream of the gauging station generally decreased between August and October sampling. White sucker density in Sculpin Creek, however, increased between August and October in 2010. At locations in Big Sandy Reservoir and in Big Sandy River downstream of the gauging station in 2010, we found particularly high densities of catostomids, nearly all of which were white suckers. One particular seine haul taken immediately below the gauging station diversion structure yielded 1,000 or more YOY catostomids (not enumerated, but nearly all white sucker). Juvenile fish were either utilizing the relatively deep pool at the base of the structure, or the diversion impeded their progress upstream, or both.

Of the native suckers captured downstream of the gauging station, flannelmouth sucker far outnumbered bluehead sucker, further supporting the idea that flannelmouth sucker would be most impacted by a barrier to upstream movement. In fact, more juvenile flannelmouth suckers were captured in that reach than at any of the other locations in 2010 and nearly half of those were found in the one seine haul immediately below the gauging station diversion structure. However, it is unknown if those fish were transported over the diversion structure during high flows, or if they moved upstream from the reservoir. The latter scenario is doubtful, given the absence of any native suckers in numerous seine samples from the reservoir. Incidentally, WGFD operated a weir just upstream of Big Sandy Reservoir from late April to early July, 2009, that primarily captured white sucker (mostly moving upstream as discharge increased) but only two flannelmouth suckers and two bluehead suckers (Atwood et al. 2011). Miller (1978) stated more than 30 years ago that the spread of white sucker throughout the drainage and in Big Sandy Reservoir, in particular, was already a problem. During a survey in 1972, gill net sampling captured 393 white suckers, 22 flannelmouth suckers, and no bluehead suckers, although that species was believed to occupy the reservoir (Miller 1978). Recent gill net surveys conducted by WGFD (unpublished data) captured very few native catostomids and all were flannelmouth suckers: one in 1988, three in 1991, none in 1992, none in 1994, and one in 1997. More intensive sampling in 2004, which employed both gill and trap nets to detect burbot and targeted native catostomids near the reservoir inflow, resulted in no flannelmouth or bluehead suckers but captured 1,548 white suckers in one night of trap netting (WGFD, unpublished data). The numbers of native catostomids and flannelmouth suckers, in particular, found below the gauging station during our 2010 seine sampling is certainly a concern. But if native suckers no longer survive in Big Sandy Reservoir to move upstream and reproduce, perhaps the direct impacts of a barrier on native species are irrelevant and indirect benefits from exclusion of non-native species (white sucker, in particular) become more important.

We compared seine sample density patterns in this study to those for collections in the Green River, Browns Park National Wildlife Refuge, Colorado, 2002–2009 (Table 21), which is subject to hydrologic conditions similar to our study area in the Big Sandy River. Densities were only slightly lower than in the Big Sandy River, but patterns were similar: higher densities in summer collections than autumn collections and highest densities for white sucker (Bestgen et al. 2007b). Mean densities in both studies were higher than those calculated for combined sucker species in seine samples collected from 350 km (mostly alluvial) of the Green River, Utah, 1979–1988: approximately 0.02 catostomids/m^2 (Haines and Tyus 1990). Given the greater size of the mainstem Green River and sampling protocols there, it is not surprising that seine hauls in the Big Sandy River would produce higher densities. We note that our seine sampling was limited to areas of established access, which may not have been where YOY catostomids were congregating as discharge dropped. Thus, areas of high catostomid concentrations may have been missed and river-wide densities may be even higher than those observed. Identifying and monitoring specific deep pools or backwaters known to support YOY suckers and/or implementing a systematic sampling protocol would provide accurate and consistent measures of retention and evaluation of potential barrier impacts.

In our sampling of the Big Sandy River, the ratio of native flannelmouth and bluehead suckers to non-native white suckers in 2009 drift samples was 3:1, but only 1:1 in later seine samples, suggesting a lack of recruitment in native sucker populations. Flannelmouth sucker made up a higher percent of larval catostomid drift than subsequent YOY seine samples, while white and bluehead sucker proportions doubled from larval drift to YOY in seine samples. However, larval bluehead and white suckers were collected in higher proportions at middle and upstream drift net stations BS2 and BS3 than at downstream station BS1. We only sampled those larval drift stations once or twice per week, so there is a reasonable chance that drift peaks (perhaps only a couple days in duration) were not sampled and that the two species were underrepresented in drift samples. We observed the opposite trend in overall ratios in 2010: the ratio of native suckers to non-native suckers in drift samples approached 1:1, but native suckers outnumbered white suckers by a 2:1 ratio in seine samples upstream of the gauging station that year. Flannelmouth sucker made up a smaller proportion of 2010 larval drift than in 2009 and its proportion decreased considerably in subsequent YOY seine samples taken upstream of the gauging station and in Sculpin Creek. Proportion of white sucker at the same locations also decreased between drift and seine samples in 2010. Bluehead sucker proportions, however, increased: 8% of catostomids in larval drift samples and 58% of catostomids in subsequent YOY seine samples. The high overall proportion of bluehead suckers in 2010 seine samples was a result of the high incidence of that species in samples near site BS3: 90% of catostomids. Bluehead suckers only made up 2–14% of catostomids in seine samples from all other locations. Again, upstream drift stations were sampled less frequently than downstream station BS1, resulting in possible underrepresentation of all species in drift net samples from those stations compared to subsequent seine sampling.

We should not necessarily expect YOY retention observed in this study to reflect our larval drift abundance results. In fact, Bestgen et al. (1998) found no concurrence between abundance of drifting Colorado pikeminnow *Ptychocheilus lucius* larvae and subsequent juvenile recruitment over several study years, and noted the increasing importance of non-native species to native fish recruitment. The impetus for this study – investigating potential impacts of a barrier to movement of non-native species – demonstrates the recognition of the threat of non-native species to native catostomids in the Big Sandy River. Nonetheless, the effect of discharge on retention of YOY catostomids in the Big Sandy River should not be discounted: protracted high flows in 2009 undoubtedly transported more larvae downstream and possibly into Big Sandy Reservoir than average flows (or even a single, higher-than-average peak, such as in 2010), resulting in low YOY densities in seine sampling. While one might assume that both non-native predation and discharge should affect native and non-native catostomids equally, the extended spawning season we calculated for white sucker in 2009 (11–21 d longer than bluehead and flannelmouth suckers, respectively) would give that species an advantage in recruitment over the more limited spawning periods of native suckers. Furthermore, we estimated that flannelmouth suckers commenced spawning as much as two weeks earlier than bluehead suckers during this study. More flannelmouth sucker embryos may have hatched and been available for drift during peak flows, resulting in greater transport of that species out of the system and fewer YOY in later sampling.

During a 2009 effort by WGFD to remove non-native species from the Big Sandy River by electrofishing, white suckers made up 27% of all catostomids, salmonids, and burbot captured (juveniles and adults), while flannelmouth and bluehead suckers made up only 11 and 10%, respectively (Atwood et al. 2011). Very few of the native suckers captured were YOY (<100 mm TL) and the remainder were adults. Removal efforts in 2010, however, produced very different results: white suckers accounted for only 10% of all fish captured, while flannelmouth and bluehead suckers made up 17 and 15%, respectively, and included higher numbers of juvenile fish. Non-native, predaceous burbot made up 11% of captures in 2009 and 18% in 2010, but were captured in similar numbers each year (approximately 600). The increases in native catostomids bode well for non-native species removal efforts as well as potential positive effects of a proposed barrier to movement of non-native species upstream from Big Sandy Reservoir, and were echoed by the lower white sucker and higher bluehead sucker proportions in our 2010 seine samples. The timing of WGFD removal efforts may also have influenced the size structures of native and white suckers observed in our seine samples from both 2009 and 2010. Given the variable results of all recent sampling and comparisons to other systems, we cannot say without a doubt that enough flannelmouth and bluehead sucker YOY are retained in the system to maintain populations in the Big Sandy River. However, each species likely produces and retains adequate individuals in some (but not necessarily the same) years and may demonstrate improved recruitment with the aid of non-native species control measures.

This study provided valuable data regarding previously undocumented spawning periods and early life history of flannelmouth, bluehead, and white sucker occupying the Big Sandy River, a priority management sub-drainage for the state of Wyoming. Continued drift net and seine sampling in more average water years will help managers better understand implications of potential non-native fish management actions and provide useful baseline ecological information for these catostomid populations living at the northernmost portion of their ranges under a variety of hydrologic conditions.

CONCLUSIONS

- Peak discharges in the Big Sandy River were higher in 2009 and 2010 than the historical average
- Flannelmouth, bluehead, and white sucker reproduced in the Big Sandy River in 2009 and 2010
- We estimated in both 2009 and 2010 that flannelmouth sucker spawned mostly prior to peak runoff and bluehead sucker spawned as runoff began in the Big Sandy River; white sucker spawned prior to the peak in both years and throughout the peak in 2009
- Thermal characteristics may be more important spawning cues than discharge levels

- Larval catostomid abundance in the Big Sandy River varied by species and year and could be affected by several factors, including: adult abundance and spawning success, embryo survival, non-native species abundance, and environmental variables, such as discharge

- Flannelmouth sucker are more at risk of loss to Big Sandy Reservoir than bluehead sucker

- Young-of-the-year and juvenile catostomid retention in the Big Sandy River varied by species, season, location, and year and did not directly correspond to larval abundance

- Flannelmouth sucker made up the smallest proportion of catostomids in combined seine samples from the Big Sandy River in 2009 and 2010

- Big Sandy Reservoir is a large source population of non-native white suckers with few native catostomids surviving there

- Native catostomids may produce and retain enough individuals to maintain their populations in the Big Sandy River if non-native species suppression continues

Recommendations

- Estimate downstream transport of native catostomid larvae into Big Sandy Reservoir during years of more average discharge levels

- Identify and monitor specific, perennially-occupied micro-habitats within the Big Sandy River for retention of young-of-the-year and juvenile catostomids

- Control populations of non-native species in the Big Sandy River above Big Sandy Reservoir

- Monitor levels of hybridization between native and non-native catostomids in the Big Sandy River

Acknowledgements

We would like to thank Wyoming Game and Fish Department for funding this project. This study would not have been possible without the field work conducted by Glenn Brenner, C. Tate Wilcox, Danielle Saye, Lindsey Luzania, Chris Craft, Jennifer Charles, Robert Granger, and Bill Kohler. Laboratory assistance was provided by C. Tate Wilcox, Sean Seal, Angela Hill, Emily Bloom, and Jennifer Austin. We are grateful for river access provided by several landowners and property managers: John Erramouspe, Richard Smith, Joe and Twila Butner, Pete Arambel, and Bill Taliaferro. We would also like to thank

Wyoming Game and Fish Department employees, particularly Diana Sweet, Bobby Compton, Kevin Gelwicks, and Dave Zafft for planning and logistical support, as well as Brad Garner and Paul Atwood for sharing pertinent data. Reviews by Pete Cavalli, Annika Walters, and Paul Atwood greatly improved this report.

LITERATURE CITED

Atwood, P. M., K. A. Handley, and R. M. Kieth. 2011. Using mechanical removal and weirs to conserve bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*), and roundtail chub (*Gila robusta*) within the Green River drainage of Wyoming, 2009 and 2010. DRAFT Administrative Report, Wyoming Game and Fish Department, Fish Division, Cheyenne, Wyoming.

Bailey, M. M. 1972. Age, growth, reproduction, and food of the burbot, *Lota lota* (Linnaeus), in southwestern Lake Superior. Transactions of the American Fisheries Society 101(4):667-674.

Baxter, G. T., and J. R. Simon. 1970. Wyoming Fishes. Wyoming Game and Fish Department. Bulletin 4. 168 pp.

Baxter, G. T., and M. D. Stone. 1995. Fishes of Wyoming. Wyoming Game and Fish Department, Cheyenne, Wyoming.

Bestgen, K. R., R. T. Muth, and M. A. Trammell. 1998. Downstream transport of Colorado squawfish larvae in the Green River drainage: temporal and spatial variation in abundance and relationships with juvenile recruitment. Final Report, Colorado River Recovery Implementation Program Project Number 32, Denver, Colorado.

Bestgen, K. R., C. D. Walford, A. A. Hill, and J. A. Hawkins. 2007a. Native fish response to removal of non-native predator fish in the Yampa River, Colorado. Final Report, Colorado River Recovery Implementation Program Project Number 140, Denver, Colorado.

Bestgen, K. R., K. A. Zelasko, and C. T. Wilcox. 2007b. Non-native fish removal in the Green River, Lodore and Whirlpool canyons, 2002-2006, and fish community response to altered flow and temperature regimes, and non-native fish expansion. Final report, Colorado River Recovery Implementation Program Project Number 115, Denver, Colorado.

Bezzerides, N., and K. R. Bestgen. 2002. Status review of roundtail chub *Gila robusta*, flannelmouth sucker *Catostomus latipinnis* and bluehead sucker *Catostomus discobolus* in the Colorado River Basin. Final Report to Bureau of Reclamation. Contribution 118, Larval Fish Laboratory, Colorado State University, Fort Collins, Colorado.

Carlson, C. A., and R. T. Muth. 1989. The Colorado River: lifeline of the American Southwest. Pages 220-239 *in* D. P. Dodge, editor Proceedings of the International Large River Symposium. Canadian Special Publication of Fisheries and Aquatic Sciences 106, Ottawa.

Carter, J. G., V. A. Lamarra, and R. J. Ryel. 1986. Drift of larval fishes in the upper Colorado River. Journal of Freshwater Ecology 3(4):567 - 577.

Chart, T. E., and E. P. Bergersen. 1992. Impact of mainstream impoundment on the distribution and movements of the resident flannelmouth sucker (Catostomidae: *Catostomus latipinnis*) population in the White River, Colorado. The Southwestern Naturalist 37(1):9-15.

Childs, M. R., R. W. Clarkson, and A. T. Robinson. 1998. Resource use by larval and early juvenile native fishes in the Little Colorado River, Grand Canyon, Arizona. Transactions of the American Fisheries Society 127(4):620-629.

Clarkson, R. W., and M. R. Childs. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River Basin big-river fishes. Copeia 2000(2):402-412.

Compton, R. I. 2007. Population fragmentation and white sucker introduction affect populations of bluehead suckers, flannelmouth suckers, and roundtail chubs in a headwater stream system, Wyoming. Master's Thesis. University of Wyoming, Laramie.

Dauwalter, D. C., J. S. Sanderson, J. E. Williams, and J. R. Sedell. 2011. Identification and implementation of native fish conservation areas in the Upper Colorado River Basin. Fisheries 36(6):278 - 288.

Douglas, M. R., and M. E. Douglas. 2007a. Genetic structure of flannelmouth sucker (*Catostomus latipinnis*) across the Colorado River Basin, with emphasis on populations in the state of Wyoming. Final report to Wyoming Game and Fish Department, WGFD Agreement #100/06, Cheyenne, Wyoming.

Douglas, M. R., and M. E. Douglas. 2007b. Molecular genetic assessment of hybrid suckers (*Catostomidae*) in the Upper Green River of Wyoming. Final report to Wyoming Game and Fish Department, WGFD Agreement #100/06, Cheyenne, Wyoming.

Ellsworth, C., T. Tyler, and S. VanderKooi. 2010. Using spatial, seasonal, and diel drift patterns of larval Lost River suckers *Deltistes luxatus* (Cypriniformes: Catostomidae) and shortnose suckers *Chasmistes brevirostris* (Cypriniformes: Catostomidae) to help identify a site for a water withdrawal structure on the Williamson River, Oregon. Environmental Biology of Fishes 89(1):47-57.

Gelwicks, K., C. J. Gill, A. Kern, and R. Keith. 2009. Current status of roundtail chub, flannelmouth sucker, and bluehead sucker in the Green River drainage of Wyoming. Fish Division Administrative Report. Wyoming Game and Fish Department, Cheyenne, Wyoming.

Haines, G. B. 1995. Effects of temperature on hatching success and growth of razorback sucker and flannelmouth sucker. Final Report, Colorado River Recovery Implementation Program Project Number 5e, Denver, Colorado.

Haines, G. B., and H. M. Tyus. 1990. Fish associations and environmental variables in age-0 Colorado squawfish habitats, Green River, Utah. Journal of Freshwater Ecology 5(4):9.

Hedrick, T. N., K. R. Bestgen, and K. D. Christopherson. 2009. Entrainment of semi-buoyant beads and razorback sucker, *Xyrauchen texanus*, larvae into flood plain wetlands of the middle Green River, Utah. Final Report, Upper Colorado River Endangered Fish Recovery Program, Project Number C-6/RZ-ENTR, Denver, Colorado.

Hubert, W. A., D. Dufek, J. Deromedi, K. Johnson, S. Roth, and D. Skates. 2008. Burbot in the Wind River Drainage of Wyoming: knowledge of stocks and management issues. American Fisheries Society Symposium 59:187-199.

McAda, C. W., and R. S. Wydoski. 1983. Maturity and fecundity of the bluehead sucker, *Catostomus discobolus* (Catostomidae), in the Upper Colorado River Basin, 1975-76. The Southwestern Naturalist 28(1):120-123.

McAda, C. W., and R. S. Wydoski. 1985. Growth and reproduction of the flannelmouth sucker, *Catostomus latipinnis*, in the Upper Colorado River Basin, 1975-1976. Great Basin Naturalist 45(2):281-286.

Miller, D. D. 1978. Comprehensive survey of the Big Sandy River. Fish Division Completion Report, Project 4077-01-6402. Wyoming Game and Fish Department, Cheyenne, Wyoming.

Miller, D. D., and D. L. Weitzel. 2003. Management considerations for native non-game fishes of Wyoming. Fish Division Administrative Report. Wyoming Game and Fish Department, Cheyenne, Wyoming.

Minckley, W. L., and J. E. Deacon, editors. 1991. Battle against extinction: Native fish management in the American West. University of Arizona Press, Tucson, Arizona.

Olden, J. D., N. L. Poff, and K. R. Bestgen. 2006. Life-history strategies predict fish invasions and extirpations in the Colorado River Basin. Ecological Monographs 76(1):25-40.

Petts, G. E. 1984. Impounded rivers: perspectives for ecological management. John Wiley and Sons, New York, New York.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks, and J. C. Stromberg. 1997. The Natural Flow Regime. BioScience 47(11):769-784.

Reinert, T. R., T. A. Will, C. A. Jennings, and W. T. Davin. 2004. Use of egg surrogates to estimate sampling efficiency of striped bass eggs in the Savannah River. North American Journal of Fisheries Management 24:704-710.

Robinson, A. T., and M. R. Childs. 2001. Juvenile growth of native fishes in the Little Colorado River and in a thermally modified portion of the Colorado River. North American Journal of Fisheries Management 21(4):809-815.

Robinson, A. T., R. W. Clarkson, and R. E. Forrest. 1998. Dispersal of larval fishes in a regulated river tributary. Transactions of the American Fisheries Society 127(5):772-786.

Senecal, A. C., K. R. Gelwicks, P. A. Cavalli, and R. M. Keith. 2009. WGFD Plan for the Three Species in the Green River drainage of Wyoming; 2009-2014. Fish Division Administrative Report. Wyoming Game and Fish Department, Cheyenne, Wyoming.

Snyder, D. E., and R. T. Muth. 2004. Catostomid fish larvae and early juveniles of the Upper Colorado River Basin - morphological descriptions, comparisons, and computer-interactive key. Colorado Division of Wildlidfe, Technical Publication Number 42.

Stanford, J. A., J. V. Ward, W. J. Liss, C. A. Frissell, R. N. Williams, J. A. Lichatowich, and C. C. Coutant. 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research & Management 12:391-413.

Sweet, D. E. 2007. Movement patterns and habitat associations of native and introduced catostomids in a tributary system of the Colorado River. Master's Thesis. University of Wyoming, Laramie.

Tyus, H. M., and G. B. Haines. 1991. Distribution, habitat use, and growth of age-0 Colorado squawfish in the Green River Basin, Colorado and Utah. Transactions of the American Fisheries Society 120(1):79 - 89.

Utah Division of Wildlife Resources. 2006. Rangewide conservation agreement for roundtail chub *Gila robusta*, bluehead sucker *Catostomus discobolus*, and flannelmouth sucker *Catostomus latipinnis*. Publication Number 06-18 prepared for Colorado River Fish and Wildlife Council, Salt Lake City, Utah.

Weitzel, D. L. 2002a. Conservation and status assessments for the bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*), roundtail chub (*Gila robusta*), and leatherside chub (*Gila copei*): rare fishes west of the Continental Divide, Wyoming. Fish Division Administartive Report. Wyoming Game and Fish Department, Cheyenne, Wyoming.

Weitzel, D. L. 2002b. Conservation and status assessment of Wyoming's common suckers: white sucker (*Catostomus commersoni*), mountain sucker (*Catostomus platyrhynchus*), longnose sucker (*Catostomus catostomus*), Utah sucker (*Catostomus ardens*), quillback (*Carpoides cyprinus*), river carpsucker (*Carpoides carpio*), and shorthead redhorse (*Maxostoma macrolepidotum*). Fish Division Administartive Report. Wyoming Game and Fish Department, Cheyenne, Wyoming.

Wheeler, C. A. 1997. Current distributions and distributional changes of fishes in Wyoming west of the Continental Divide. Master's Thesis. University of Wyoming, Laramie, Wyoming.

Wyoming Game and Fish Department. 2010. State Wildlife Action Plan. Wyoming Game and Fish Department, Cheyenne, Wyoming. Available online: http://gf.state.wy.us/SWAP2010/Plan/index.asp

Table 1. Discharge categories in cubic feet per second (cfs) and their conversions to cubic meters per second (m^3/s).

Discharge categories (cfs)	(m^3/s)
0–99	0–2.8
100–199	2.8–5.6
200–299	5.6–8.5
300–399	8.5–11.3
400–499	11.3–14.1

Table 2. Mean sampling discharges (USGS gauging station 09213500) for each drift net station in the Big Sandy River, Wyoming, 2009 and 2010. BS1, BS2, and BS3 = drift net stations located 4.0 km, 18.3 km, and 45.2 km upstream of USGS gauging station 09213500, respectively.

Station	Date range	Sets	Mean sampling discharge (m^3/s)		
			Min	Max	Mean
			2009		
BS1	16 Jun - 7 Aug	23	1.4	15.9	6.9
BS2	1 Jul - 6 Aug	8	1.4	10.1	5.0
BS3	25 Jun - 5 Aug	8	1.4	14.9	5.8
all	16 Jun - 7 Aug	39	1.4	15.9	6.3
			2010		
BS1	8 Jun - 30 Jul	35	1.3	18.7	7.4
BS2	22 Jun - 29 Jul	11	1.4	11.6	5.1
BS3	22 Jun - 28 Jul	8	1.4	9.8	4.9
all	8 Jun - 30 Jul	54	1.3	18.7	6.6

Table 3. Species composition of larvae captured at all drift net stations combined in the Big Sandy River, Wyoming, 2009 and 2010. Question marks (?) denote tentatively identified specimens.

Species	2009		2010		all	
	n	%	*n*	%	*n*	%
bluehead sucker	162	13.6	41	7.1	203	11.5
bluehead sucker?	3	0.3	4	0.7	7	0.4
flannelmouth sucker	667	55.8	199	34.7	866	49.0
flannelmouth sucker?	9	0.8	1	0.2	10	0.6
mountain whitefish			1	0.2	1	<0.1
speckled dace			1	0.2	1	<0.1
mottled sculpin	1	0.1			1	<0.1
white sucker	283	23.7	269	46.9	552	31.2
white sucker?	2	0.2	3	0.5	5	0.3
white X bluehead sucker	1	0.1			1	<0.1
flannelmouth X white sucker?	1	0.1	1	0.2	2	0.1
longnose sucker?	1	0.1	2	0.3	3	0.2
unidentified sucker	7	0.6	3	0.5	10	0.6
fathead minnow			2	0.3	2	0.1
lake chub	2	0.2			2	0.1
unidentified specimen			1	0.2	1	<0.1
embryo	56	4.7	46	8.0	102	5.8
total	1195	100.0	574	100.0	1769	100.0

Table 4. Numbers of catostomids captured, sampling times, and total volumes sampled at each drift net station in the Big Sandy River, Wyoming, 2009. BS1, BS2, and BS3 = drift net stations located 4.0 km, 18.3 km, and 45.2 km upstream of USGS gauging station 09213500, respectively; *n* = number of bluehead, flannelmouth, and white suckers captured; SE = standard error of the mean; CI = confidence interval.

station	samples	*n*	time (hr)	mean *n* /hr	SE	95% CI	volume (m^3)	mean *n* /m^3	SE	95% CI
BS1	63	817	63.6	13.4	3.43	(6.51–20.21)	20968	0.033	0.008	(0.0172–0.0491)
BS2	24	235	24.5	9.6	3.20	(2.97–16.19)	6176	0.032	0.010	(0.0106–0.0529)
BS3	24	60	23.6	2.5	0.60	(1.23 – 3.70)	8138	0.008	0.002	(0.0045–0.0125)
total	111	1112	111.7	10.2	2.10	(6.04–14.36)	35282	0.027	0.005	(0.0173–0.0376)

Table 5. Species composition of bluehead, flannelmouth, and white sucker at each drift net station in the Big Sandy River, Wyoming, 2009. BS1, BS2, and BS3 = drift net stations located 4.0 km, 18.3 km, and 45.2 km upstream of USGS gauging station 09213500, respectively.

Species	Station							
	BS1		BS2		BS3		Total	
	n	%	*n*	%	*n*	%	*n*	%
bluehead sucker	44	5.4	96	40.9	22	36.7	162	14.6
flannelmouth sucker	593	72.6	61	26.0	13	21.7	667	60.0
white sucker	180	22.0	78	33.2	25	41.7	283	25.4
total	817	100.0	235	100.0	60	100.0	1112	100.0

Table 6. Numbers of catostomids captured, sampling times, and total volumes sampled at each drift net station in the Big Sandy River, Wyoming, 2010. BS1, BS2, and BS3 = drift net stations located 4.0 km, 18.3 km, and 45.2 km upstream of USGS gauging station 09213500, respectively; *n* = number of bluehead, flannelmouth, and white suckers captured; SE = standard error of the mean; CI = confidence interval.

station	samples	*n*	time (hr)	mean *n*/hr	SE	95% CI	volume (m^3)	mean *n*/m^3	SE	95% CI
BS1	95	343	95.0	3.5	0.74	(2.05–4.99)	29603	0.011	0.0022	(0.0064–0.0151)
BS2	30	54	30.8	1.7	0.41	(0.90–2.57)	7452	0.006	0.0015	(0.0033–0.0093)
BS3	24	112	24.1	4.6	1.26	(1.98–7.21)	11118	0.009	0.0023	(0.0041–0.0135)
total	149	509	149.9	3.3	0.52	(2.30–4.37)	48173	0.010	0.0015	(0.0066–0.0125)

Table 7. Species composition of bluehead, flannelmouth, and white sucker at each drift net station in the Big Sandy River, Wyoming, 2010. BS1, BS2, and BS3 = drift net stations located 4.0 km, 18.3 km, and 45.2 km upstream of USGS gauging station 09213500, respectively.

Species	Station							
	BS1		BS2		BS3		Total	
	n	%	*n*	%	*n*	%	*n*	%
bluehead sucker	12	3.5	6	11.1	23	20.5	41	8.1
flannelmouth sucker	126	36.7	23	42.6	50	44.7	199	39.1
white sucker	205	59.8	25	46.3	39	34.8	269	52.8
total	343	100.0	54	100.0	112	100.0	509	100.0

Table 8. Target discharge categories and mean discharges sampled during drift simulation trials at low-gradient (Low) and high-gradient (High) sites in the Big Sandy River, Wyoming, 2009.

Discharge category		Mean discharge per trial (m^3/s)	
m^3/s	cfs	Low	High
0–2.8	(0–99)	2.5	2.7, 2.5
2.8–5.6	(100–199)	4.7	4.8
5.6–8.5	(200–299)	8.3	6.9
8.5–11.3	(300–399)	10.1, 10.5	10.7
11.3–14.1	(400–499)	11.7, 12.6, 13.1	12.3, 13.5, 13.6

Table 9. Mean water velocities (calculated from flow meters at mouths of 1 to 3 nets, depending on discharge) sampled at low-gradient (Low) and high-gradient (High) sites under target discharge categories during drift simulation trials in the Big Sandy River, Wyoming, 2009.

Discharge (m^3/s)	Low		High	
	velocity (m/s)	net-sets[a]	velocity (m/s)	net-sets[a]
0–2.8	0.50	27	0.40	72
2.8–5.6	0.66	27	0.67	20
5.6–8.5	0.75	24	0.71	9
8.5–11.3	0.64	72	0.90	32
11.3–14.1	0.81	98	0.84	81

[a] total number of nets set in combined trials at each site and discharge category; set times varied

Table 10. Percents of total river volume sampled and beads captured at low-gradient (Low) and high-gradient (High) sites under target discharge categories during drift simulation trials in the Big Sandy River, Wyoming, 2009. Ratios were calculated with non-rounded percents. Volumes sampled per trial are not comparable between low- and high-gradient sites due to differences in effort (number of drift nets).

Discharge (m^3/s)	Net-sets[a]	Mean % volume sampled, per trial	Mean % beads captured, per trial	Ratio (% volume:% beads)
		Low		
0–2.8	27	8.9	3.6	2:1
2.8–5.6	27	6.3	1.1	6:1
5.6–8.5	24	4.0	0.1	49:1
8.5–11.3	72	2.3	0.9	3:1
11.3–14.1	98	1.9	1.0	2:1
		High		
0–2.8	14	6.8	<0.1	68:1
2.8–5.6	10	4.1	0.2	24:1
5.6–8.5	9	1.5	0.2	8:1
8.5–11.3	16	2.5	0.8	3:1
11.3–14.1	15	2.1	0.6	3:1

[a] total number of nets (one to three per set, depending on discharge) set in combined trials at each site and discharge category

Table 11. Ranges of time elapsed (post-release of beads) to first, peak, and last captures of beads at low-gradient and high-gradient sites under target discharge categories during drift simulation trials in the Big Sandy River, Wyoming, 2009. Distances travelled by beads at each site are in parentheses.

Discharge (m^3/s)	Trials	First beads	Peak beads	Last beads
		Low-gradient (5.0 km)		
0–2.8	1	2 h 27 m–2 h 58 m	2 h 27 m–3 h 00 m	7 h 37 m–8 h 10 m
2.8–5.6	1	2 h 10 m–2 h 40 m	2 h 10 m–2 h 42 m	7 h 11 m–7 h 41 m
5.6–8.5	1	2 h 30 m–3 h 00 m	2 h 30 m–3 h 00 m	7 h 31 m–8 h 01 m
8.5–11.3	2	0 h 00 m[a]–1 h 46 m	1 h 41 m–2 h 09 m	5 h 50 m–6 h 43 m
11.3–14.1	3	0 h 19 m–1 h 52 m	1 h 36 m–2 h 03 m	4 h 53 m–7 h 51 m
		High-gradient (6.4 km)		
0–2.8	2	4 h 14 m-4 h 46 m[b]	unknown[c]	unknown[c]
2.8–5.6	1	1 h 15 m–1 h 45 m	3 h 21 m–3 h 51 m	7 h 20 m–7 h 51 m
5.6–8.5	1	2 h 01 m–2 h 31 m	2 h 31 m–3 h 01 m	4 h 01 m–4 h 31 m
8.5–11.3	1	0 h 30 m–0 h 49 m	1 h 41 m–1 h 58 m	6 h 30 m–6 h 46 m
11.3–14.1	3	0 h 26 m–1 h 51 m	1 h 32 m–1 h 56 m	5 h 23 m–6 h 21 m

[a] first beads detected during one trial between 0 h 00 m and 0 h 12 m

[b] data from one trial only; no beads had reached drift nets after 7 h 44 m in 2nd trial

[c] trials terminated after 5 h 45 m and 7 h 44 m

Table 12. Mean velocities of beads (time to travel 5.0 and 6.4 km at low- and high-gradient sites, respectively) and water (calculated from flow meters at mouths of nets) at low-gradient (Low) and high-gradient (High) sites under target discharge categories during drift simulation trials in the Big Sandy River, Wyoming, 2009.

Discharge (m^3/s)	Mean bead velocity (m/s)		Mean water velocity (m/s)		Velocity ratio (water:bead)	
	Low	High	Low	High	Low	High
0–2.8	0.29	unk[a]	0.50	0.40	1.7	unk[a]
2.8–5.6	0.33	0.45	0.66	0.67	2.0	1.5
5.6–8.5	0.33	0.56	0.75	0.71	2.3	1.3
8.5–11.3	0.59	0.71	0.64	0.90	1.1	1.3
11.3–14.1	0.53	0.63	0.81	0.84	1.5	1.3

[a] 2 trials at this discharge level terminated after 5 h 45 m (few beads detected) and 7 h 44 m (no beads detected)

Table 13. Habitats sampled by seine hauls in the Big Sandy River, Wyoming, 2009. BS1, BS2, BS3, and Buckskin Crossing are main channel locations approximately 4.0 km, 18.3 km, 45.2, and 86.6 km upstream of USGS gauging station 09213500, respectively. Sculpin Creek is a tributary located near Big Sandy River RK 45.3.

Habitat	Location					
	BS1	BS2	BS3	Buckskin Crossing	Sculpin Creek	Total
backwater	6	3	4	2		15
shoreline	6	4	2	1	1	14
side channel	4	4	5			13
eddy	3	3	1			7
scour pool	2	2		1	1	6
run					5	5
riffle		1			2	3
pool	2					2
isolated pool				1		1
undercut bank					1	1
Total	23	17	12	5	10	67

Table 14. Numbers and total area of seine hauls in the Big Sandy River, Wyoming, 2009. BS1, BS2, BS3, and Buckskin Crossing are main channel locations approximately 4.0 km, 18.3 km, 45.2, and 86.6 km upstream of USGS gauging station 09213500, respectively. Sculpin Creek is a tributary located near Big Sandy River RK 45.3.

Location	Seine hauls	Area seined (m^2)	% of total area	Fish captured?	
				No	Yes
BS1	23	641	40	8	15
BS2	17	466	29	5	12
BS3	12	261	16	1	11
Buckskin Crossing	5	89	6		5
Sculpin Creek	10	155	10		10
Total	67	1612	100	14	53

Table 15. Species composition of combined seine haul samples at five locations in the Big Sandy River, Wyoming, 2009. BS1, BS2, BS3, and Buckskin Crossing are main channel locations approximately 4.0 km, 18.3 km, 45.2, and 86.6 km upstream of USGS gauging station 09213500, respectively. Sculpin Creek is a tributary located near Big Sandy River RK 45.3. Question marks (?) denote tentatively identified specimens.

Species	Location					total	%
	BS1	BS2	BS3	Buckskin Crossing	Sculpin Creek		
bluehead sucker	44	353	81		2	480	19.6
bluehead sucker?		1			1	2	0.1
flannelmouth sucker	115	233	14		5	367	15.0
flannelmouth sucker?			1			1	<0.1
mountain sucker		5				5	0.2
mountain sucker?		2	1			3	0.1
mottled sculpin				23		23	0.9
speckled dace		1	14		6	21	0.9
speckled dace?			2			2	0.1
mountain whitefish		1				1	<0.1
fathead minnow	1	1			6	8	0.3
redside shiner		2	5			7	0.3
lake chub	2	90	402		176	669	27.3
salmonid				1		1	<0.1
white sucker	134	491	112	28	69	834	34.0
white sucker?	1	5			1	7	0.3
white X bluehead sucker					1	1	<0.1
flannelmouth X white sucker?		5				5	0.2
longnose sucker			2		2	4	0.2
unidentified sucker			7		2	9	0.4
total	297	1190	641	52	271	2451	100

Table 16. Species composition (%) and total length (TL) ranges of bluehead, flannelmouth, and white sucker collected in seine samples at five locations in the Big Sandy River, Wyoming, 2009. BS1, BS2, BS3, and Buckskin Crossing are main channel locations approximately 4.0 km, 18.3 km, 45.2, and 86.6 km upstream of USGS gauging station 09213500, respectively. Sculpin Creek is a tributary located near Big Sandy River RK 45.3.

Species	TL range (mm)	% composition					
		BS1 (*n* =293)	BS2 (*n* =1077)	BS3 (*n* =207)	Buckskin Crossing (*n* =28)	Sculpin Creek (*n* =76)	all locations (*n* =1681)
bluehead sucker	(12–43)	15	33	39		3	28
flannelmouth sucker	(16–55)	39	22	7		6	22
white sucker	(11–90)	46	45	54	100	91	50
total		100	100	100	100	100	100

Table 17. Habitats sampled by seine hauls in the Big Sandy River, Wyoming, 2010. Shoreline samples in "Big Sandy Reservoir" were near the inlet or lower half of the reservoir. Samples "downstream of gauging station" were in a 3.5 km stretch immediately below the gauging station (RK 0.0). BS1, BS2, BS3, and WGFD reach 21 are main channel locations approximately 4.0 km, 18.3 km, 45.2, and 63.3 km upstream of USGS gauging station 09213500, respectively. Sculpin Creek is a tributary located near Big Sandy River RK 45.3.

Habitat	Location							
	Big Sandy Reservoir	downstream of gaging station	BS1	BS2	BS3	WGFD reach 21	Sculpin Creek	Total
shoreline	19	4	11	1	3	2		40
backwater		3	5	3	6	3		20
eddy		4	2	3	3	3		15
pool		1	5	5	1	2		14
run			3			4	2	9
side channel		2		1	4	1		8
tributary				1			3	4
riffle				1			1	2
Total	19	14	26	15	17	15	6	112

Table 18. Numbers and total area of seine hauls in the Big Sandy River, Wyoming, 2010. Shoreline samples in “Big Sandy Reservoir” were near the inlet or lower half of the reservoir. Samples “downstream of gauging station” were in a 3.5 km stretch immediately below the gauging station (RK 0.0). BS1, BS2, BS3, and WGFD reach 21 are main channel locations approximately 4.0 km, 18.3 km, 45.2, and 63.3 km upstream of USGS gauging station 09213500, respectively. Sculpin Creek is a tributary located near Big Sandy River RK 45.3

Location	Seine hauls	Area seined (m^2)	% of total area	Fish captured?	
				No	Yes
Big Sandy Reservoir	19	681	27	3	16
downstream of gaging station	14	378	15	7	7
BS1	26	496	20	8	18
BS2	15	319	13		15
BS3	17	292	12	3	14
WGFD reach 21	15	267	11	1	14
Sculpin Creek	6	70	3		6
Total	112	2502	100	22	90

Table 19. Species composition of combined seine haul samples at seven locations in the Big Sandy River, Wyoming, 2010. Shoreline samples in “Big Sandy Reservoir” were near the inlet or lower half of the reservoir. Samples “downstream of gauging station” were in a 3.5 km stretch immediately below the gauging station (RK 0.0). BS1, BS2, BS3, and WGFD reach 21 are main channel locations approximately 4.0 km, 18.3 km, 45.2, and 63.3 km upstream of USGS gauging station 09213500, respectively. Sculpin Creek is a tributary located near Big Sandy River RK 45.3. Question marks (?) denote tentatively identified specimens.

Species	Location							total	%
	Big Sandy Reservoir	downstream of gaging station	BS1	BS2	BS3	WGFD reach 21	Sculpin Creek		
bluehead sucker		9[a]	3	76	1313	116	6	1523	19.6
bluehead sucker?		1		5				6	0.1
flannelmouth sucker		59[a]	38	83	58	21	11	270	3.5
flannelmouth sucker?		1						1	<0.01
mountain sucker				15		214	3	232	3.0
mountain sucker?			1		100	16		117	1.5
mottled sculpin					2	27		29	0.4
speckled dace					15	134	12	161	2.1
mountain whitefish				3		3	48	54	0.7
fathead minnow	75	207	7	4		1		294	3.8
redside shiner	24	79		1			1	105	1.4
redside shiner?		1						1	<0.01
lake chub		1	1	34	159	112	400	707	9.1
lake chub?							1	1	<0.01
lake chub x speckled dace?							1	1	<0.01
speckled dace X lake chub						1		1	<0.01
white sucker	2835	339[a]	118	391	80	140	170	4073	52.5
white sucker?				3			1	4	0.1
white X bluehead sucker		1						1	<0.01
white X flannelmouth sucker?		2						2	<0.01
flannelmouth X white sucker					2	1	1	4	0.1
longnose sucker			4		9		3	16	0.2
longnose sucker?	8	1	3		4			16	0.2
longnose sucker X ?						3		3	<0.01
longnose X bluehead sucker?							2	2	<0.01
unidentified sucker		5	8	7	82	35		137	1.8
total	2942	706	183	622	1824	824	660	7761	100

[a] approximately 50 bluehead suckers, 55 flannelmouth suckers, and 1,000 white suckers were also captured in one seine haul downstream of gauging station diversion structure, but sample was not fully enumerated

Table 20. Species composition (%) and total length (TL) ranges of bluehead, flannelmouth, and white sucker collected in seine samples at five locations in the Big Sandy River, Wyoming, 2010. BS1, BS2, BS3, and WGFD reach 21 are main channel locations approximately 4.0 km, 18.3 km, 45.2, and 63.3 km upstream of USGS gauging station 09213500, respectively. Sculpin Creek is a tributary located near Big Sandy River RK 45.3.

Species	TL range (mm)	% composition					
		BS1 (*n* =159)	BS2 (*n* =550)	BS3 (*n* =1451)	WGFD reach 21 (*n* =277)	Sculpin Creek (*n* =187)	all locations (*n* =2624)
bluehead sucker	(12–84)	2	14	90	42	3	58
flannelmouth sucker	(14–140)	24	15	4	8	6	8
white sucker	(12–156)	74	71	6	51	91	34
total		100	100	100	100	100	100

Table 21. Densities of bluehead, flannelmouth, and white suckers in seine samples from the Green River, Browns Park National Wildlife Refuge, Colorado, 2002–2009 (adapted from Bestgen et al. 2007b).

Year	bluehead sucker		flannelmouth sucker		white sucker	
	summer	autumn	summer	autumn	summer	autumn
2002	0.65	0.15	1.27	0.13	2.53	0.54
2003	0.07	0.01	0.43	0.05	0.35	0.21
2004	0.05	0.01	0.17	0.04	0.62	0.51
2005	0.03	<0.01	0.35	0.05	1.55	0.55
2006	<0.01	0.01	0.13	0.01	0.04	0.53
2007	0.03	0.01	0.60	0.01	0.94	0.90
2008	0.02	0	0.41	<0.01	2.22	0.21
2009	0	0	0	0.01	0.07	0.02

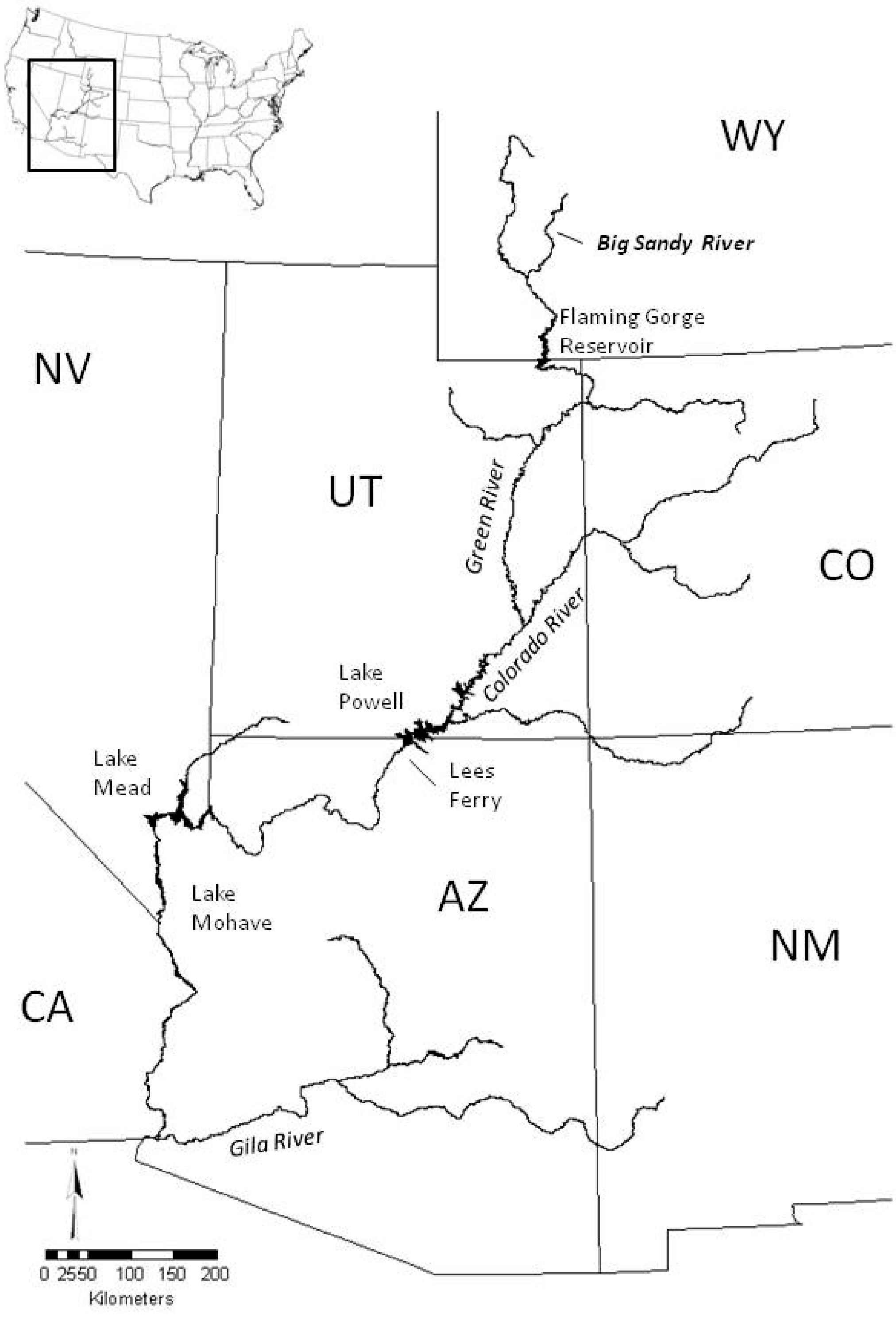

Figure 1. Map of Colorado River Basin.

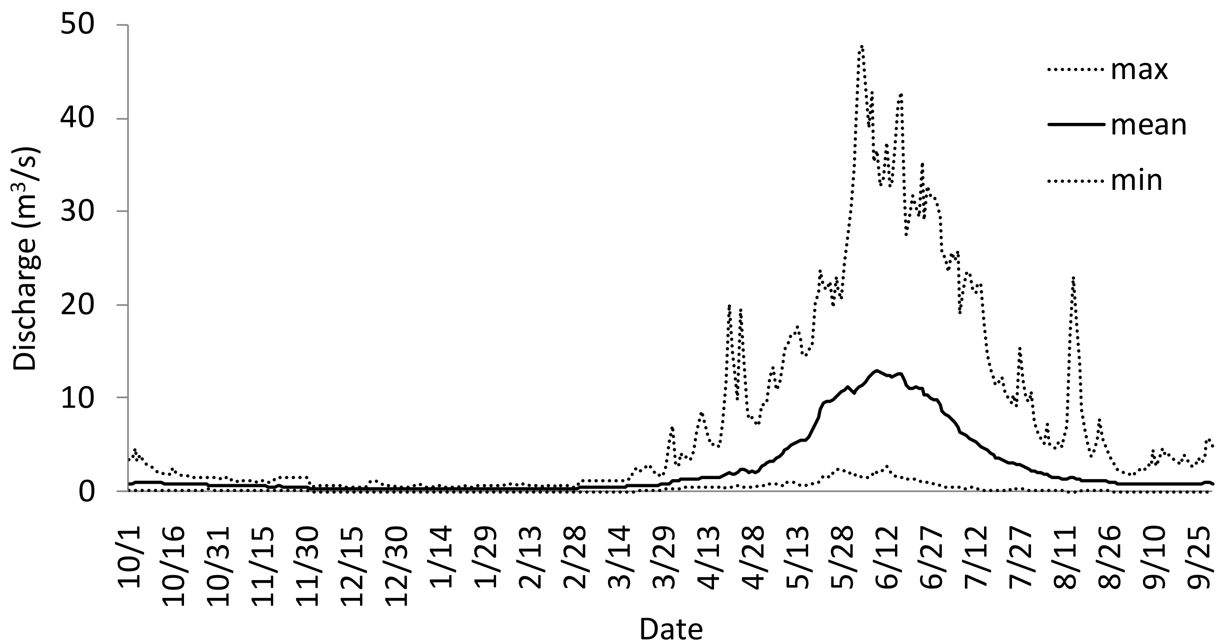

Figure 2. Mean daily discharge of the Big Sandy River, Wyoming, 1915–2008 (USGS gauging station 09213500).

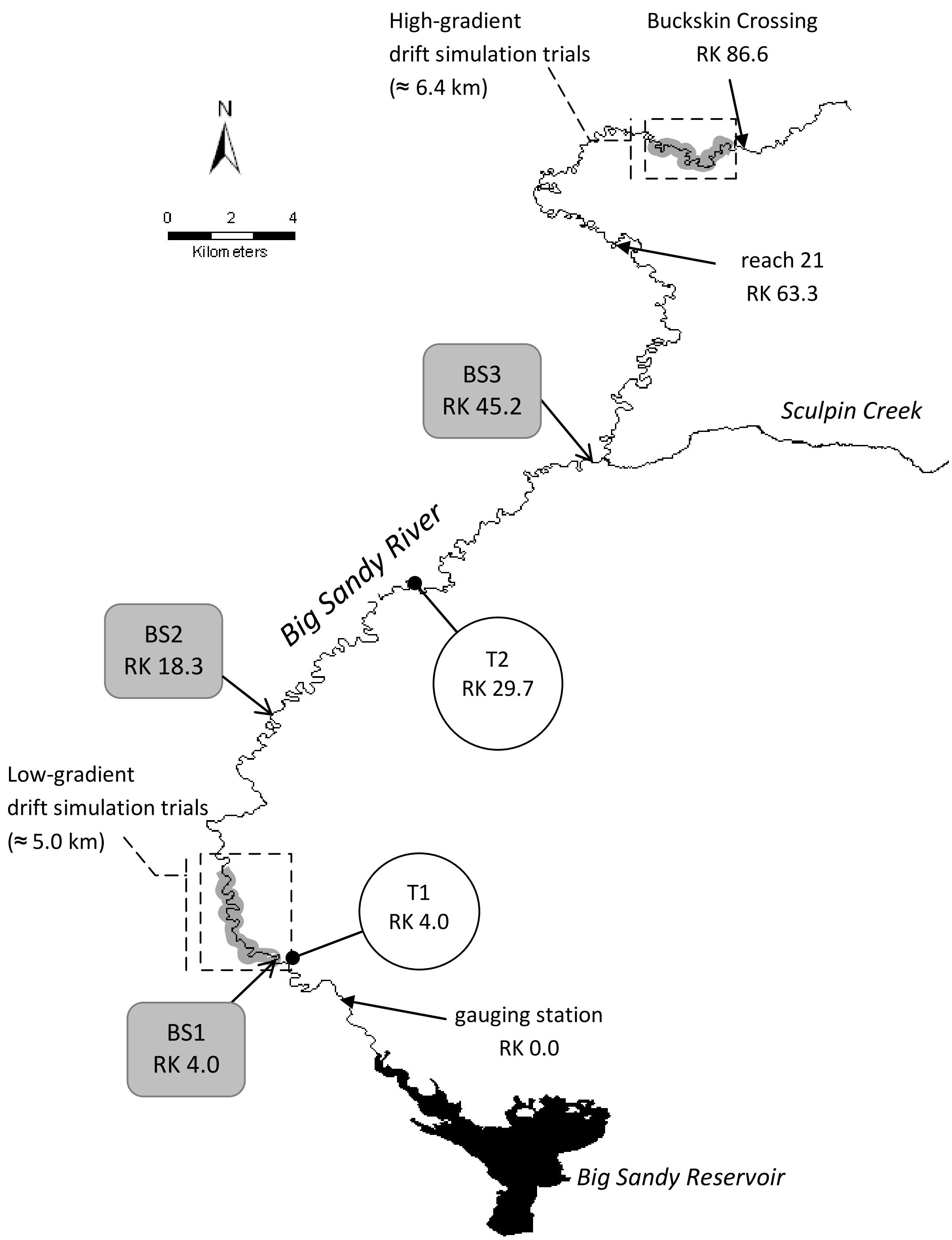

Figure 3. Study area in the Big Sandy River, Wyoming, 2009 and 2010. BS1, BS2, and BS3 = drift net stations. T1 and T2 = thermograph locations. Reach 21 = seining location.

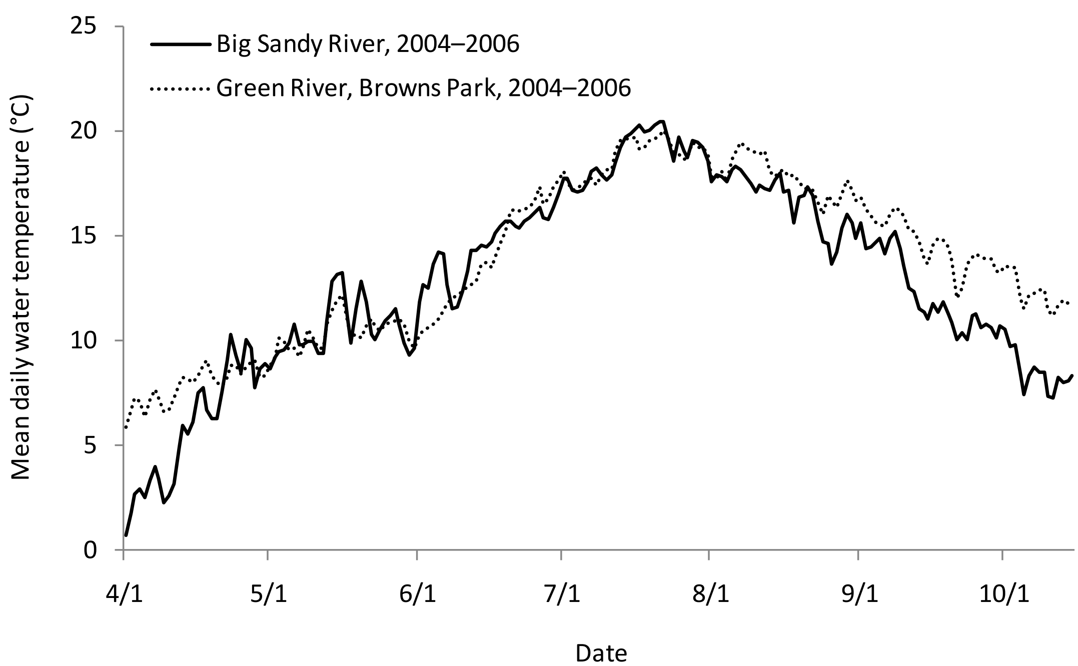

Figure 4. Mean daily water temperatures in the Big Sandy River, Wyoming (K. Gelwicks, unpublished data), and the Green River at Browns Park, Colorado (http://www.fws.gov/mountain-prairie/riverdata), 2004–2006.

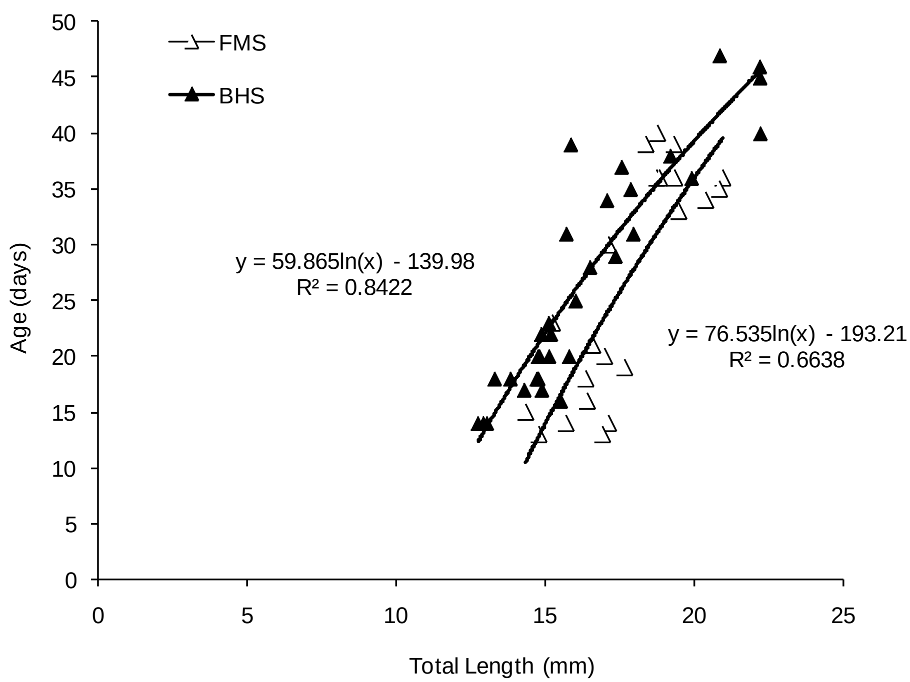

Figure 5. Length-age relationships calculated using otolith-aged flannelmouth (FMS) and bluehead (BHS) sucker larvae collected in the Green River, Colorado (from Browns Park National Wildlife Refuge to the Yampa River confluence), in 2004 (K. Bestgen, unpublished data).

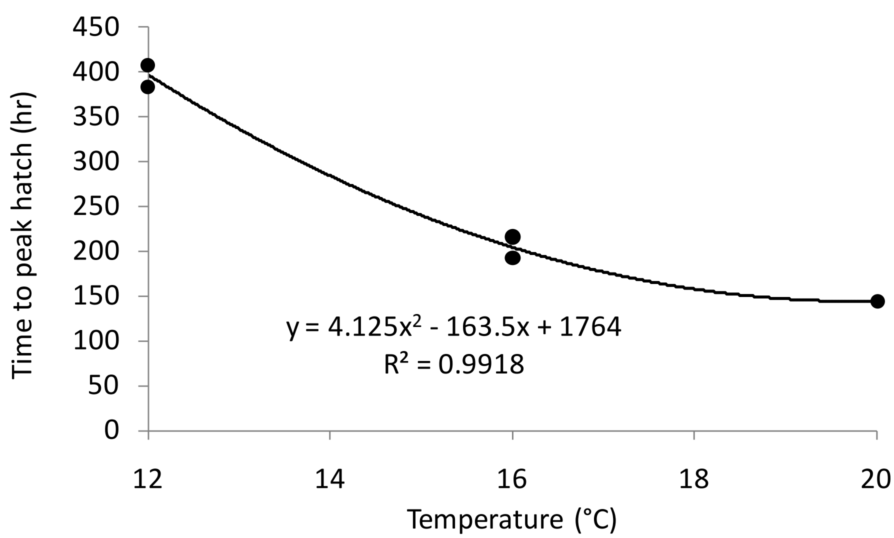

Figure 6. Temperature-dependent Incubation times calculated for flannelmouth sucker in laboratory experiments by Haines (1995).

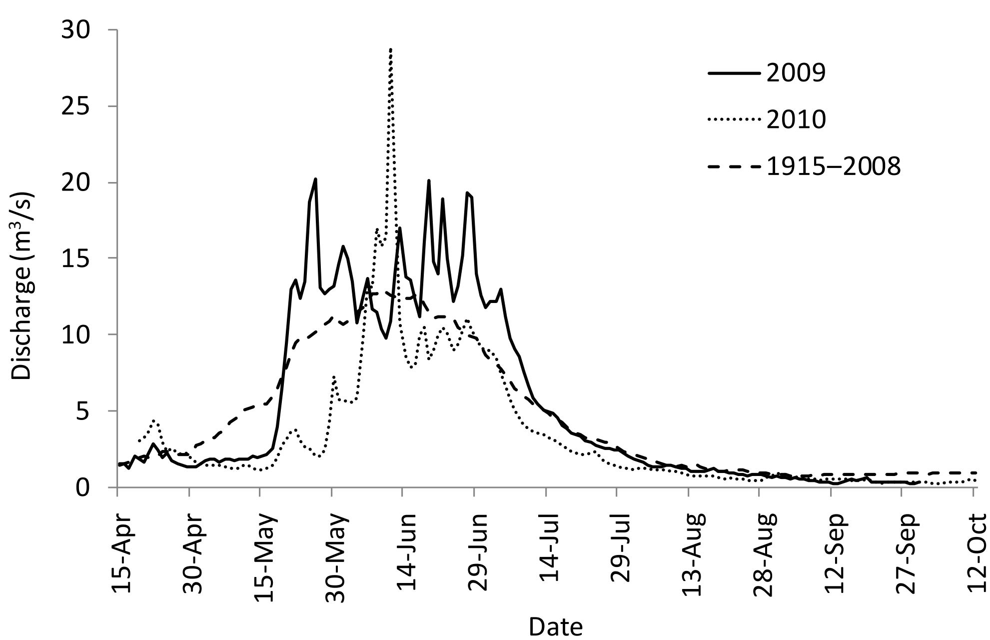

Figure 7. Mean daily discharge of the Big Sandy River, Wyoming, in 2009 and 2010 compared to 1915 through 2008 (USGS gauging station 09213500).

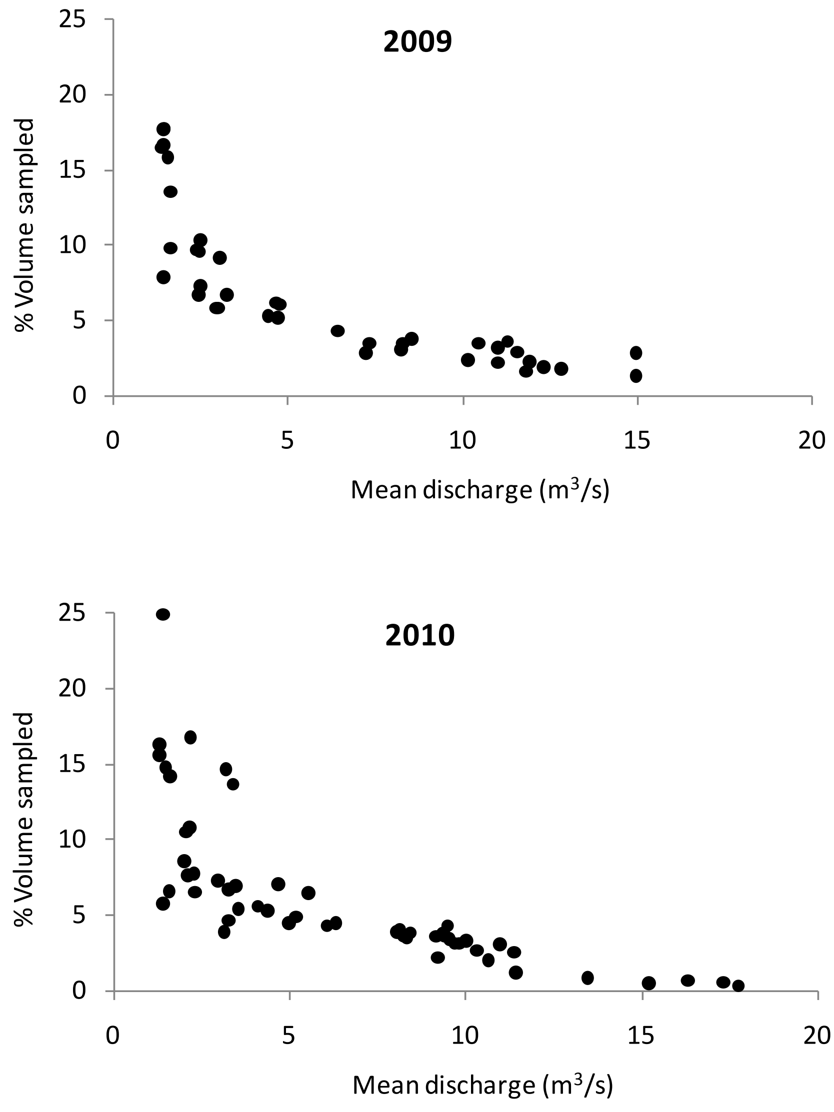

Figure 8. Percent of total river volume sampled as a function of mean discharge (USGS gauging station 09213500) during drift net sampling in the Big Sandy River, Wyoming, 2009 and 2010.

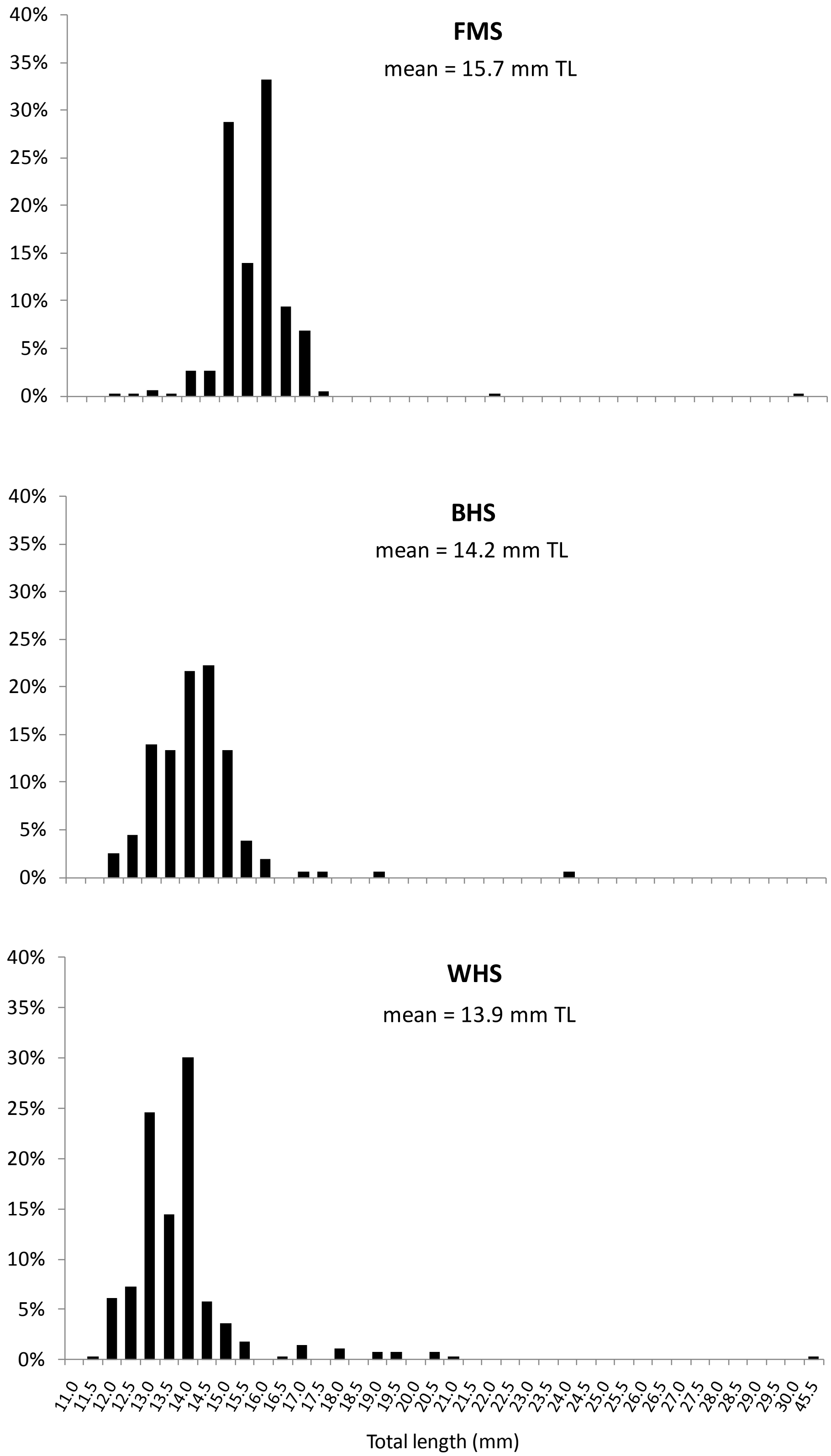

Figure 9. Length frequencies of flannelmouth (FMS), bluehead (BHS), and white (WHS) suckers in drift net samples from all stations in the Big Sandy River, Wyoming, 2009.

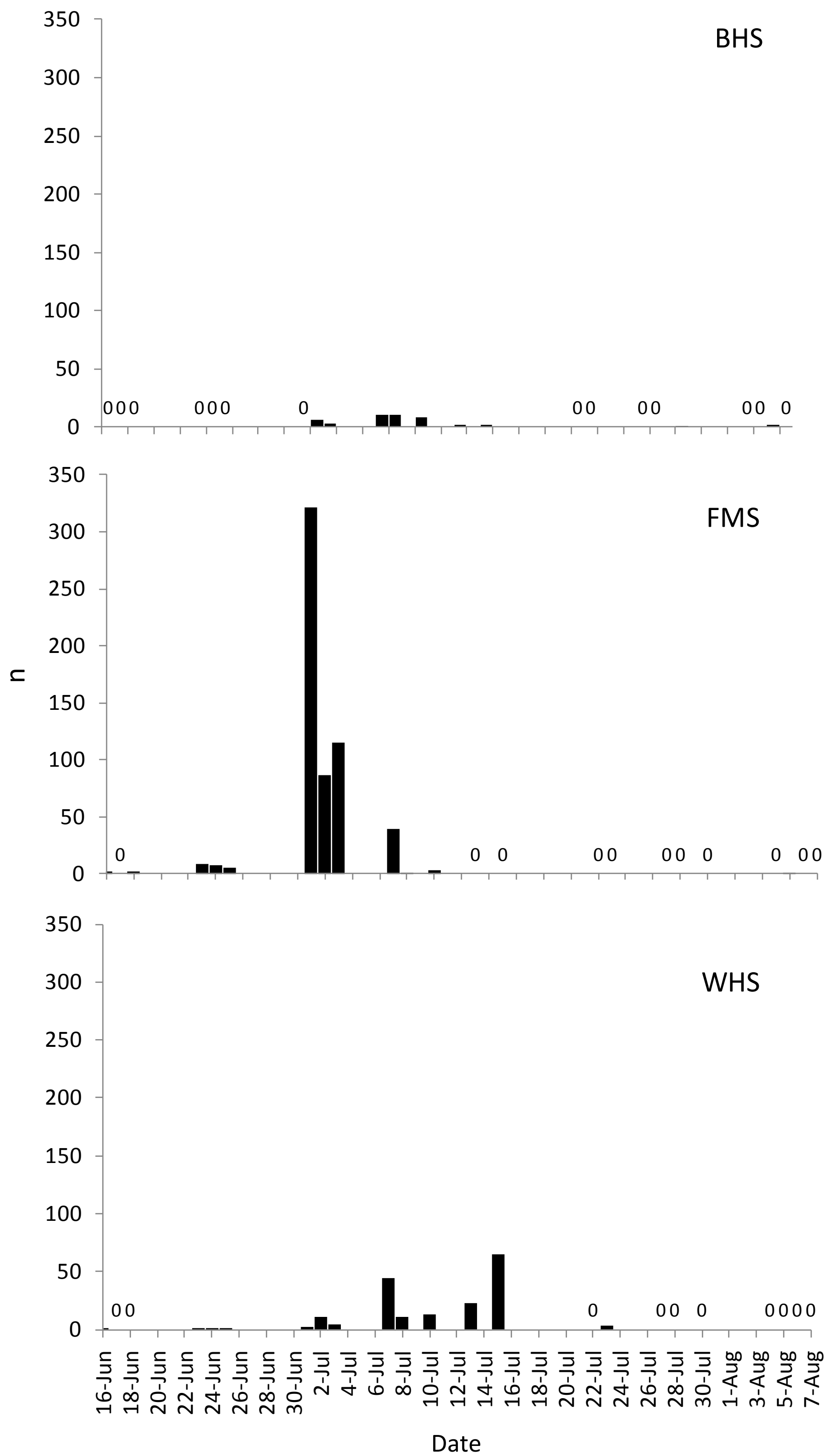

Figure 10. Numbers of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers per date in drift net samples from downstream station BS1 (4.0 km upstream of USGS gauging station 09213500) in the Big Sandy River, Wyoming, 16 June–7 August 2009. Zeroes indicate when sampling occurred but no fish were captured.

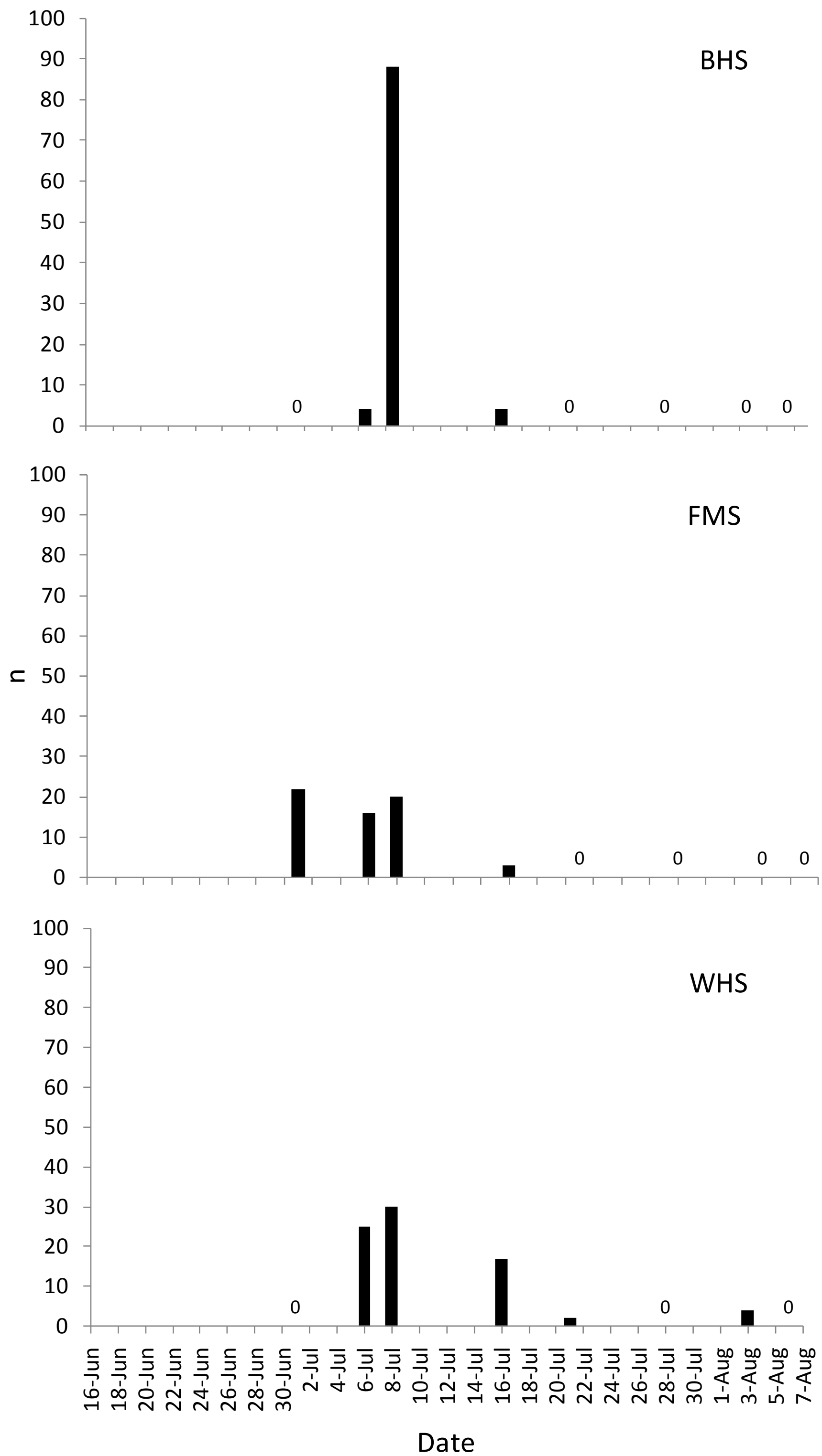

Figure 11. Numbers of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers per date in drift net samples from middle station BS2 (18.3 km upstream of USGS gauging station 09213500) in the Big Sandy River, Wyoming, 1 July–6 August 2009. Zeroes indicate when sampling occurred but no fish were captured.

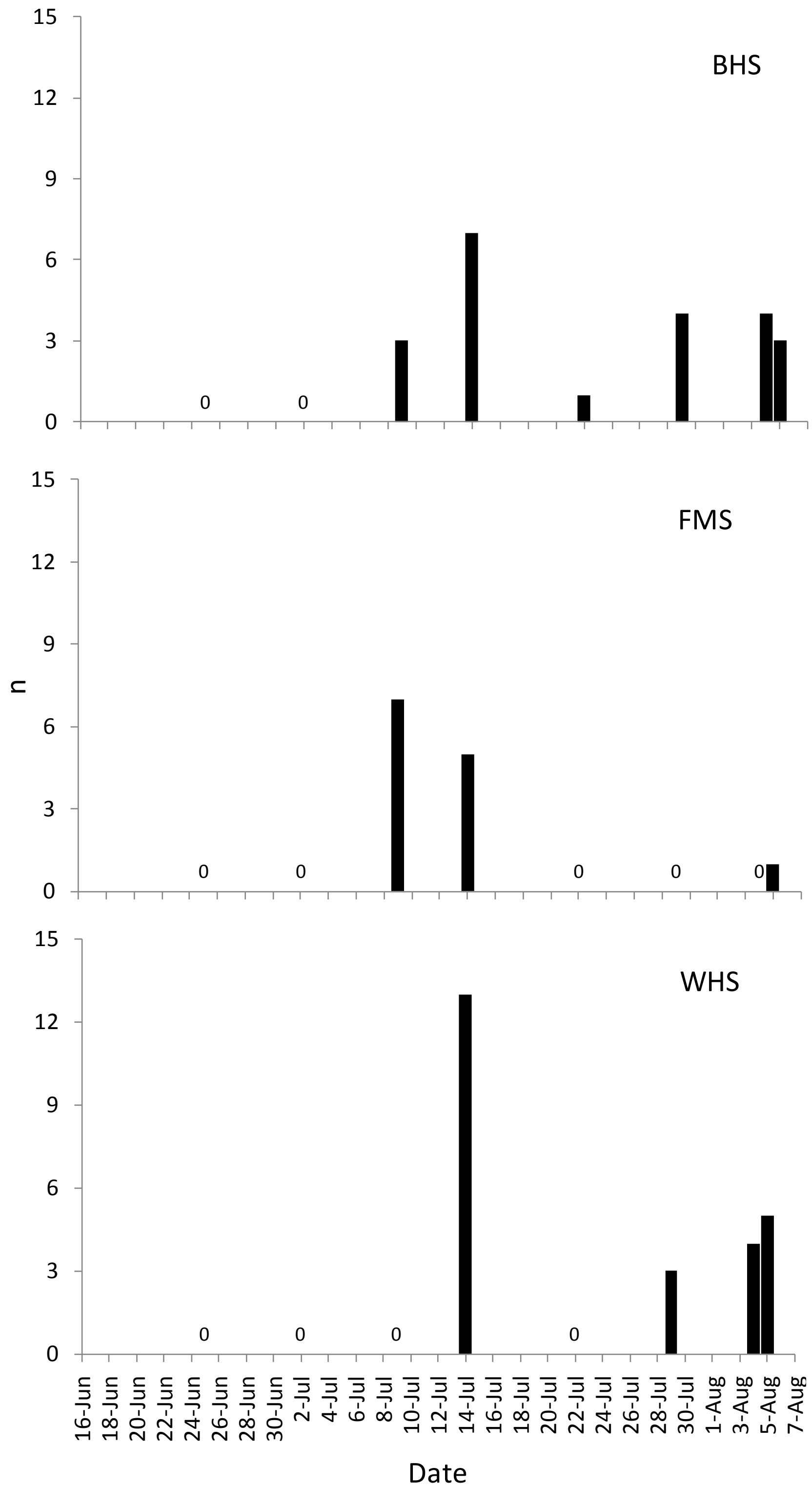

Figure 12. Numbers of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers per date in drift net samples from upstream station BS3 (45.2 km upstream of USGS gauging station 09213500) in the Big Sandy River, Wyoming, 25 June–5 August 2009. Zeroes indicate when sampling occurred but no fish were captured.

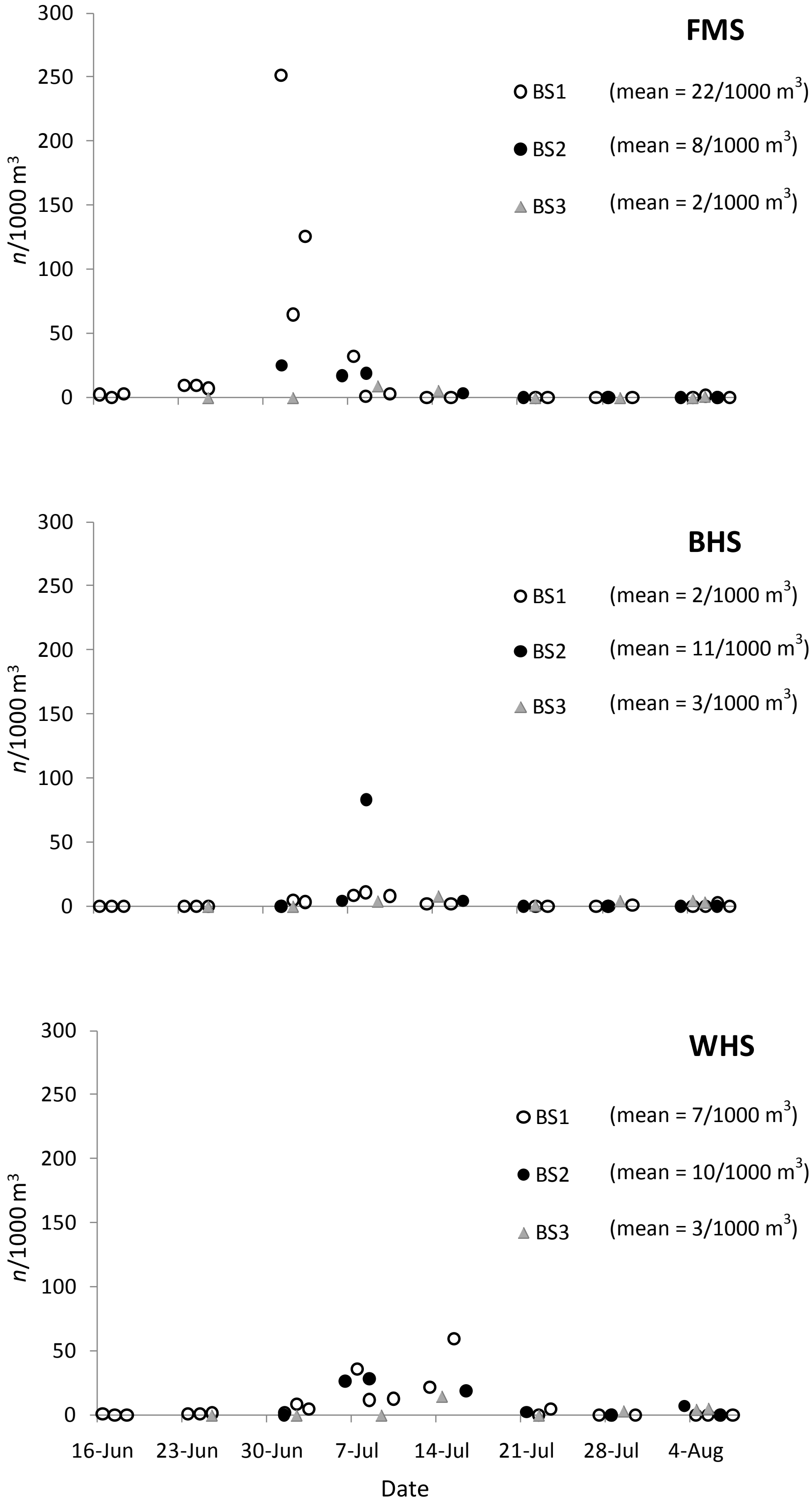

Figure 13. Densities (number per volume of water sampled, n/1000 m^3) of flannelmouth (FMS), bluehead (BHS), and white (WHS) suckers per date in drift net samples from the Big Sandy River, Wyoming, 2009. BS1, BS2, and BS3 = drift net stations located 4.0 km, 18.3 km, and 45.2 km upstream of USGS gauging station 09213500, respectively.

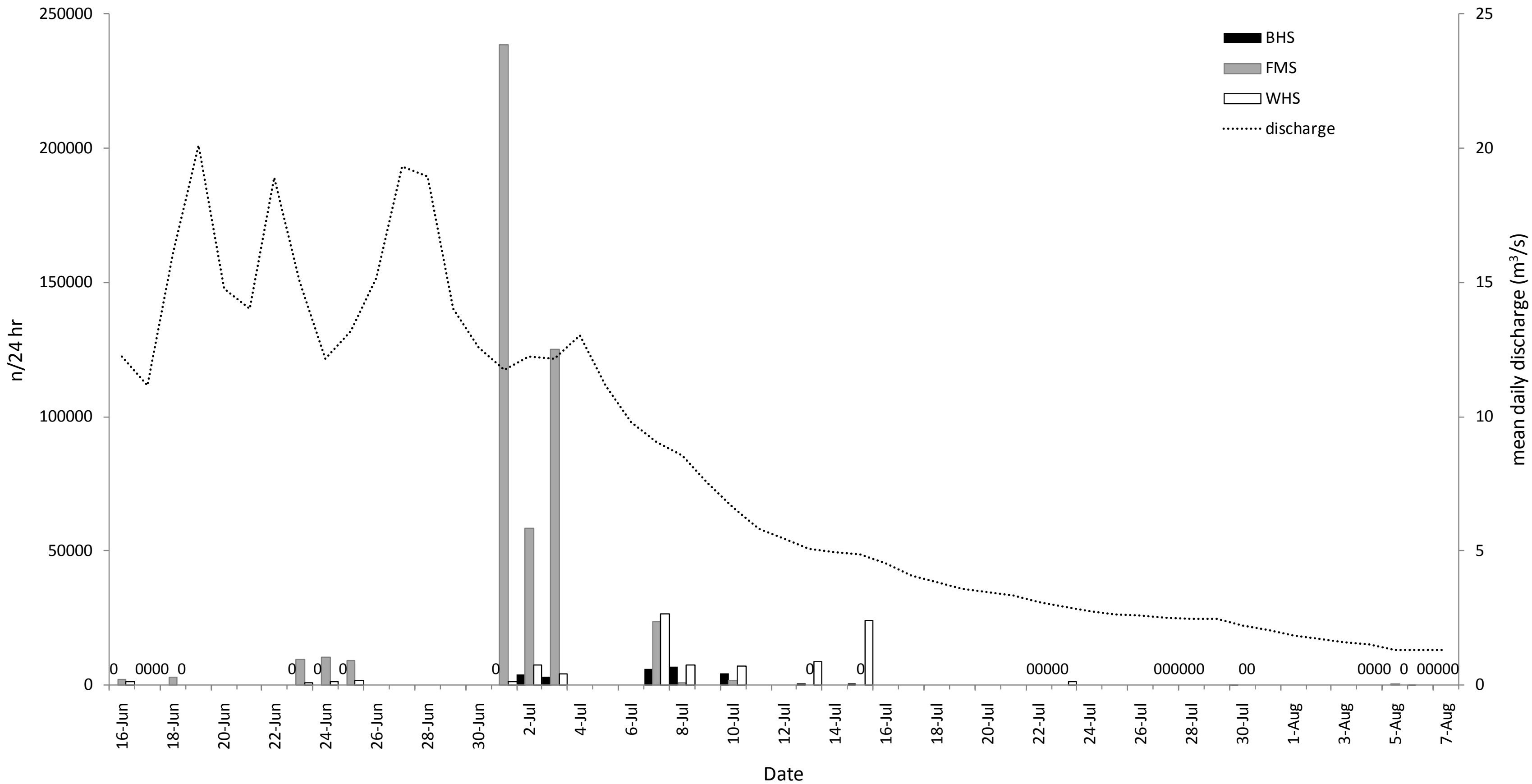

Figure 14. Estimated numbers of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers that drifted past downstream drift net station BS1 (4.0 km upstream of USGS gauging station 09213500) on sampling days in the Big Sandy River, Wyoming, 2009. Zeroes indicate when sampling occurred but no fish were captured.

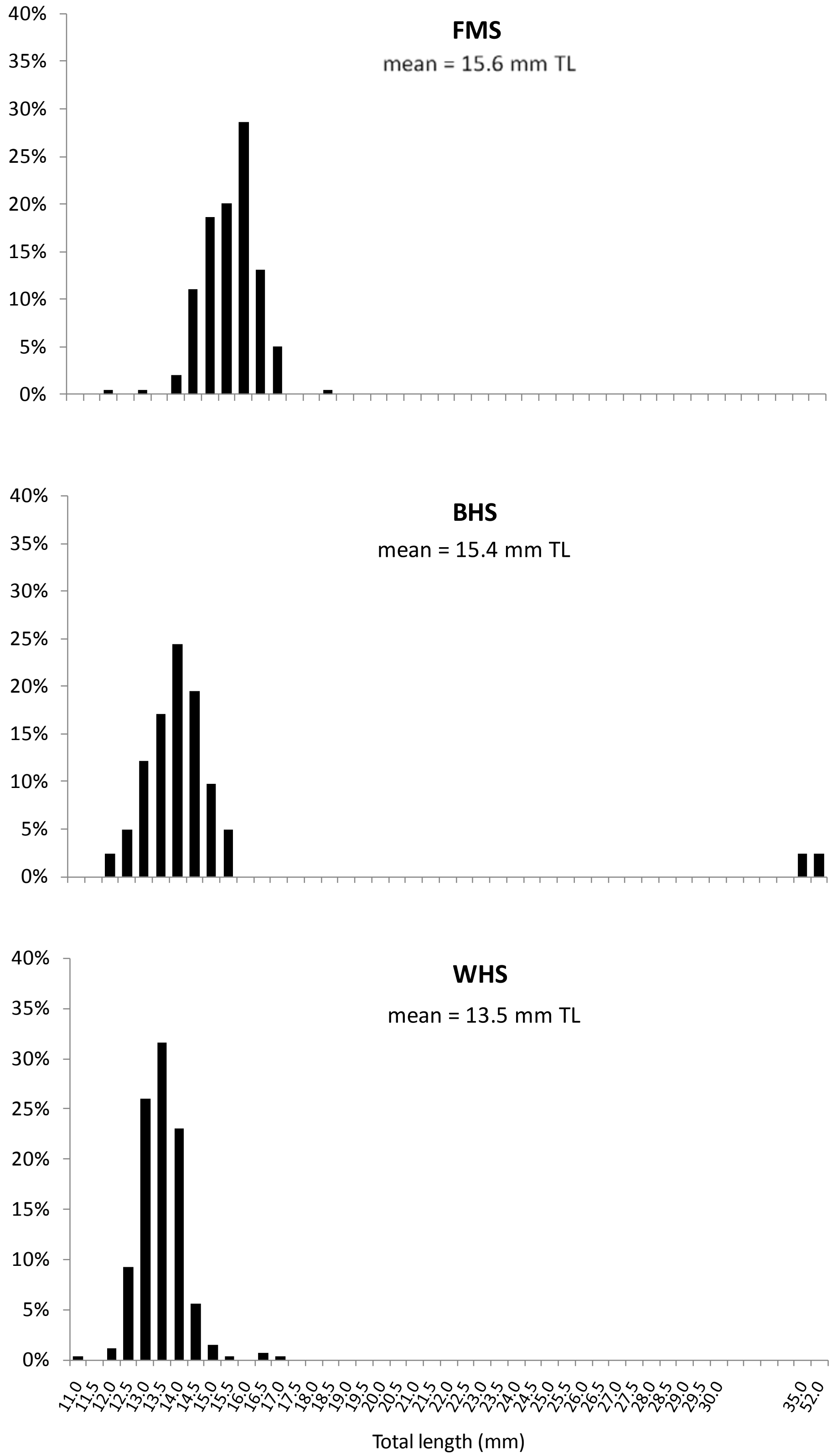

Figure 15. Length frequencies of flannelmouth (FMS), bluehead (BHS), and white (WHS) suckers in drift net samples from all stations in the Big Sandy River, Wyoming, 2010.

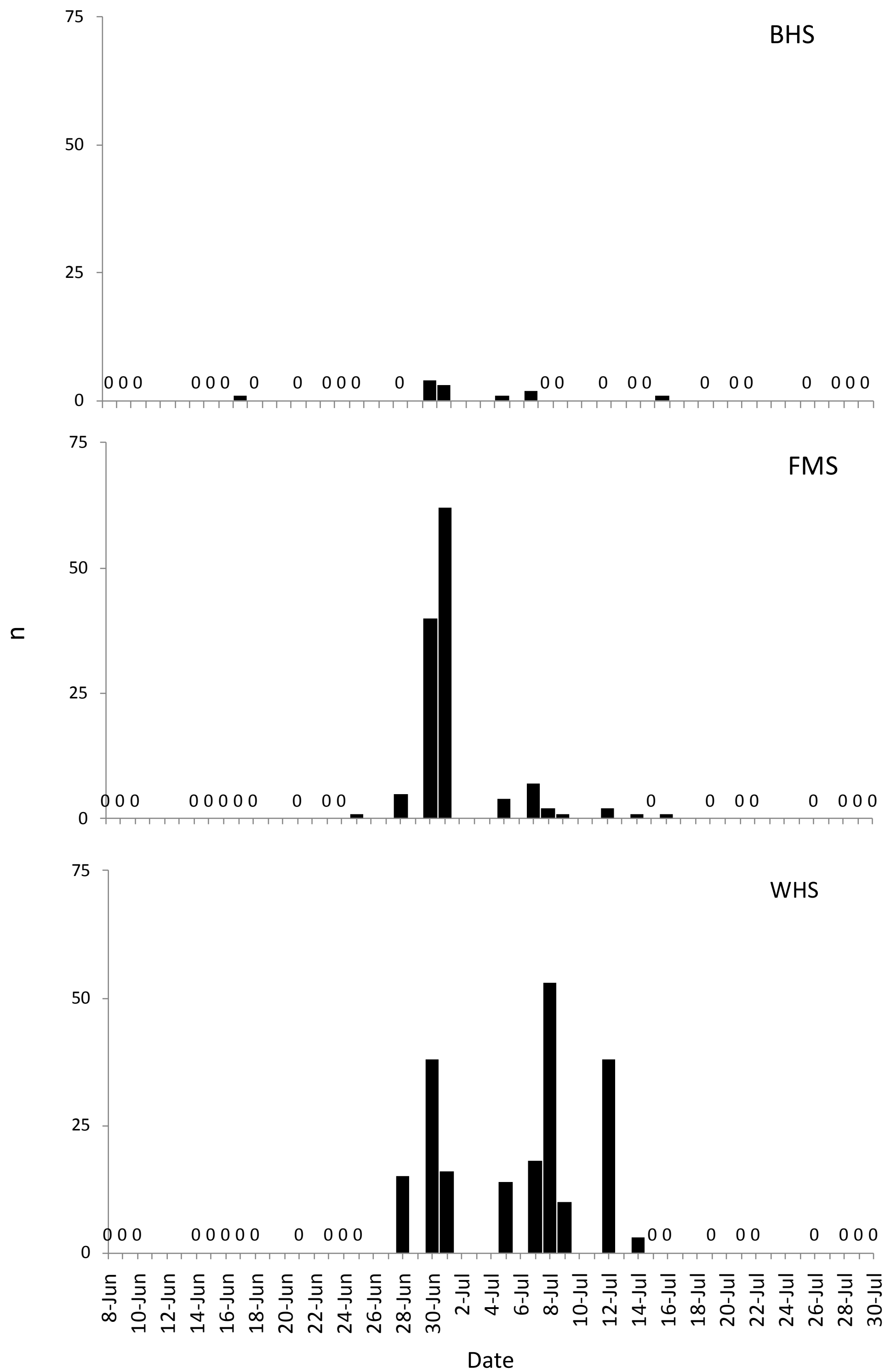

Figure 16. Numbers of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers per date in drift net samples from downstream station BS1 (4.0 km upstream of USGS gauging station 09213500) in the Big Sandy River, Wyoming, 8 June–30 July 2010. Zeroes indicate when sampling occurred but no fish were captured. Sampling on 8, 9, 17 and 30 June, as well as 21 July, included two occasions (morning and evening).

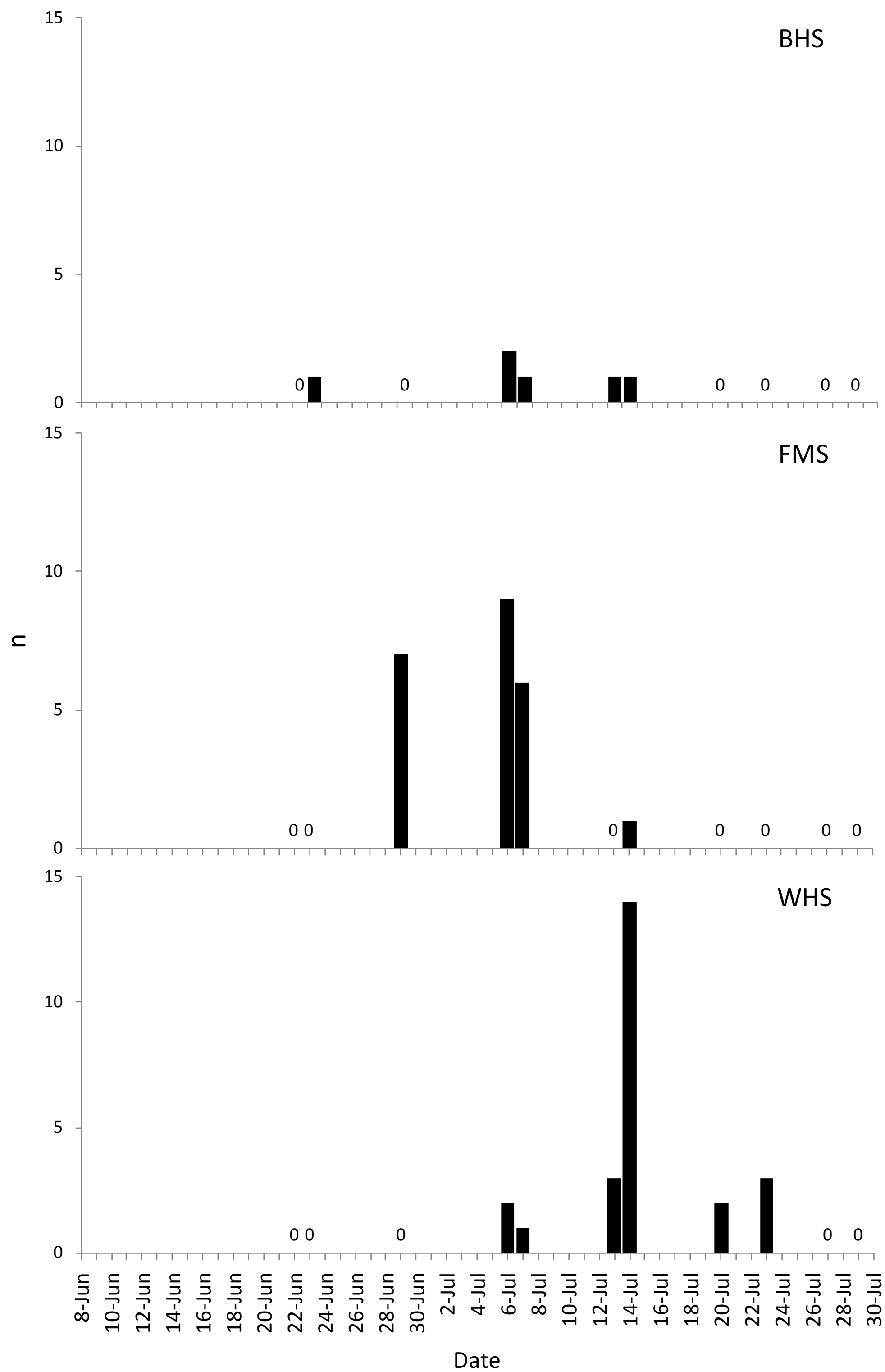

Figure 17. Numbers of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers per date in drift net samples from middle station BS2 (18.3 km upstream of USGS gauging station 09213500) in the Big Sandy River, Wyoming, 22 June–29 July 2010. Zeroes indicate when sampling occurred but no fish were captured.

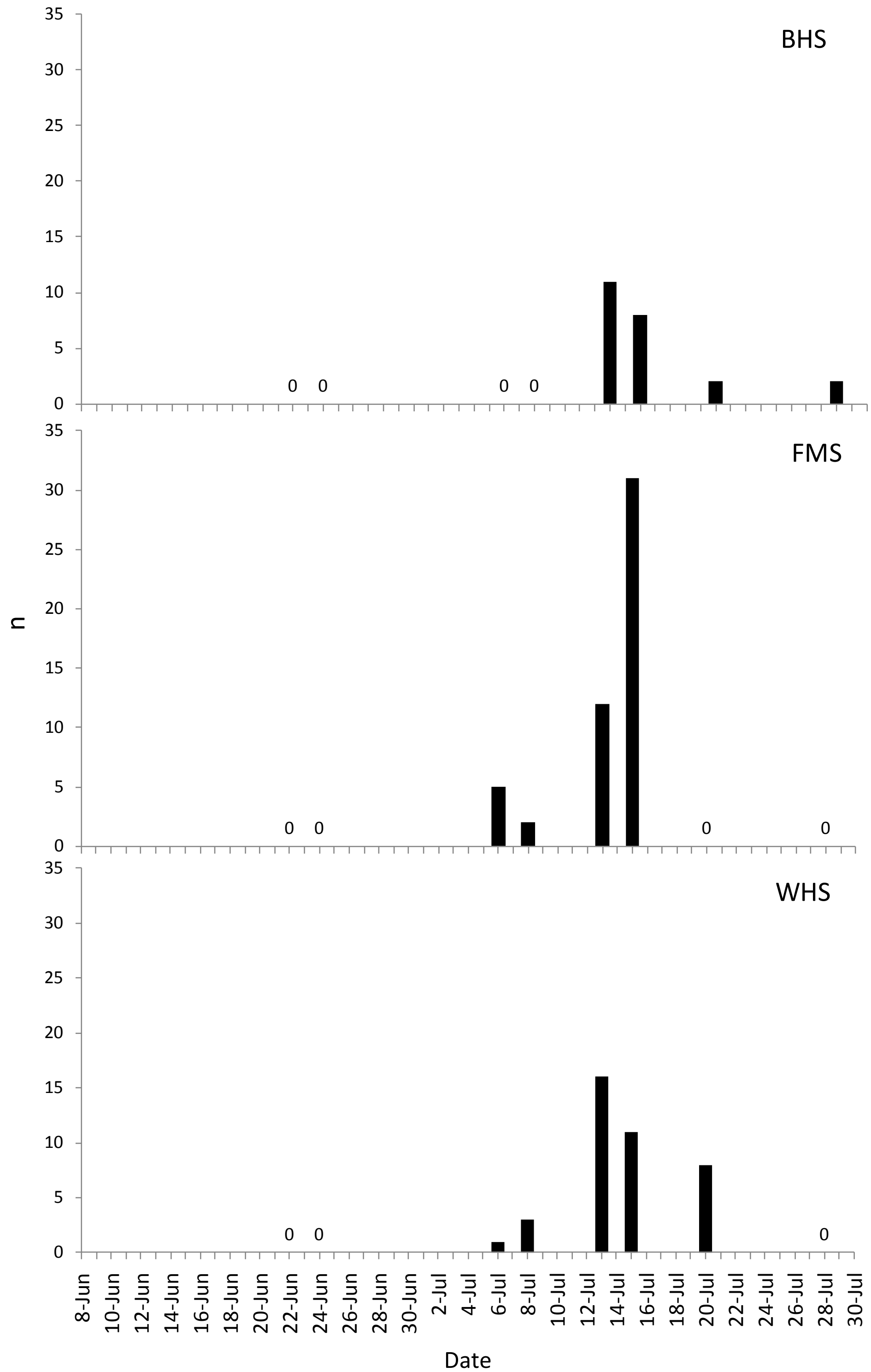

Figure 18. Numbers of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers per date in drift net samples from upstream station BS3 (45.2 km upstream of USGS gauging station 09213500) in the Big Sandy River, Wyoming, 22 June–28 July 2010. Zeroes indicate when sampling occurred but no fish were captured.

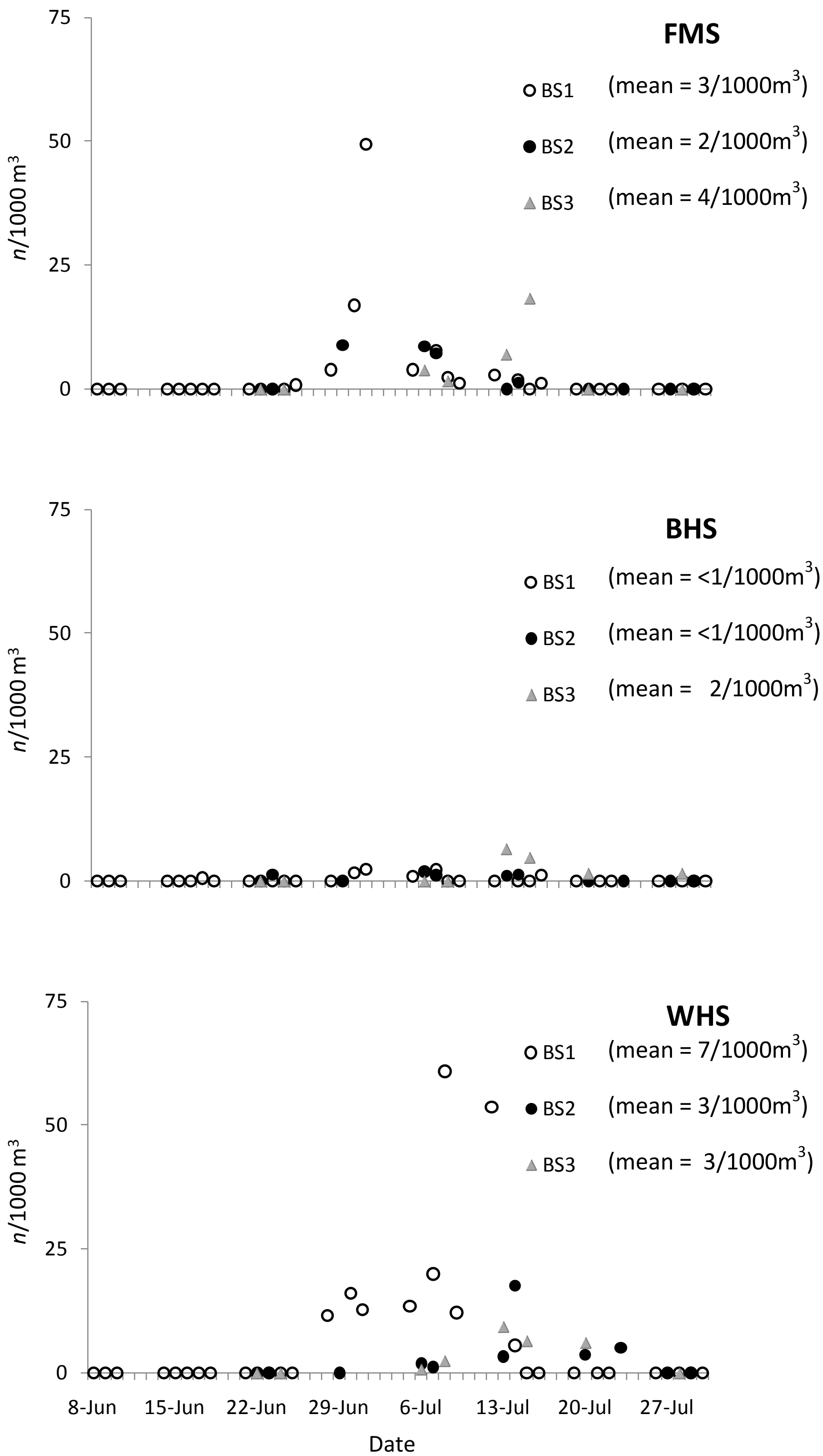

Figure 19. Densities (number per volume of water sampled, n/1000 m^3) of flannelmouth (FMS), bluehead (BHS), and white (WHS) suckers per date in drift net samples from the Big Sandy River, Wyoming, 2010. BS1, BS2, and BS3 = drift net stations located 4.0 km, 18.3 km, and 45.2 km upstream of USGS gauging station 09213500, respectively.

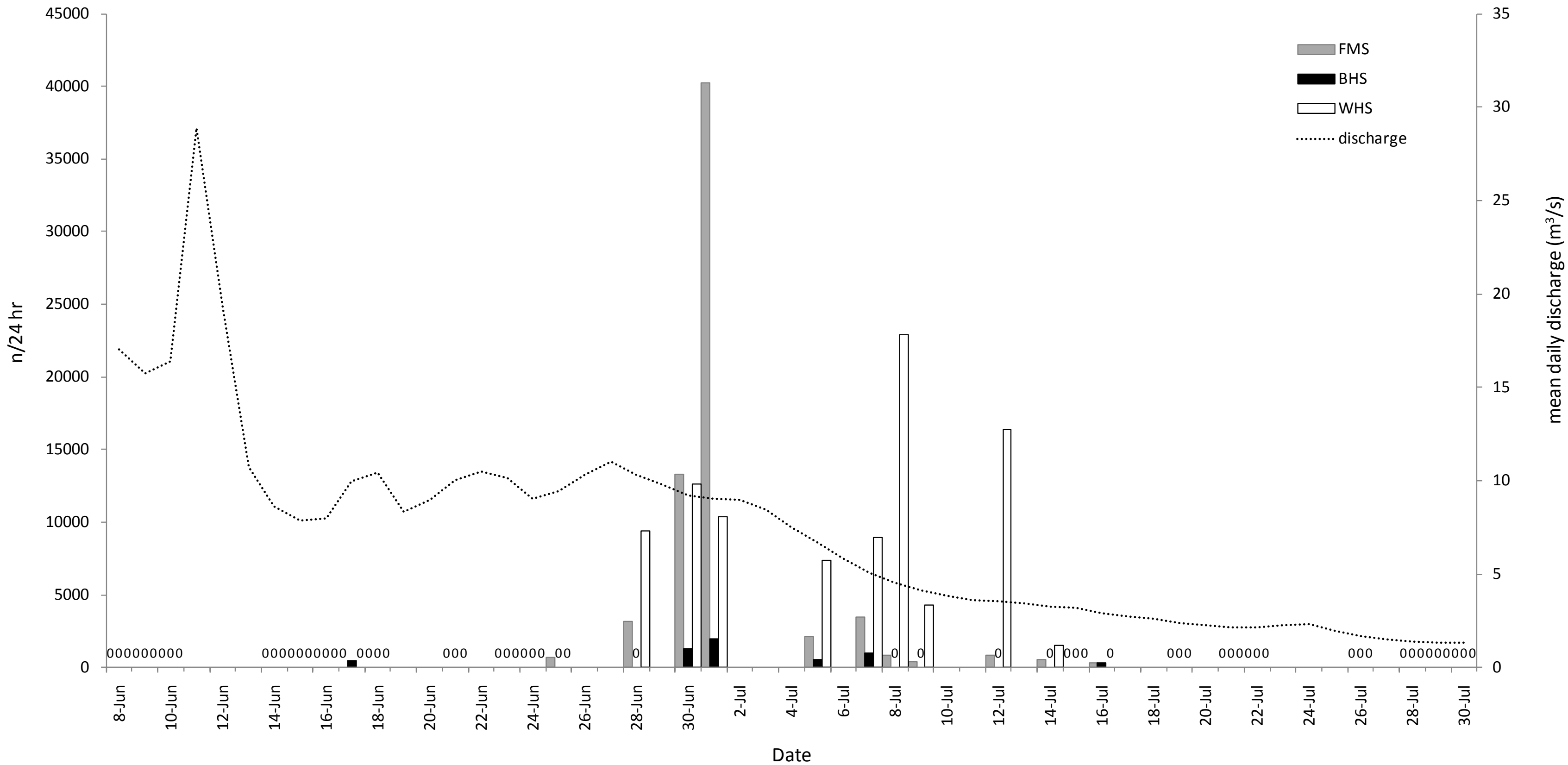

Figure 20. Estimated numbers of flannelmouth (FMS), bluehead (BHS), and white (WHS) suckers that drifted past downstream drift net station BS1 (4.0 km upstream of USGS gauging station 09213500) on sampling days in the Big Sandy River, Wyoming, 2010. Zeroes indicate when sampling occurred but no fish were captured.

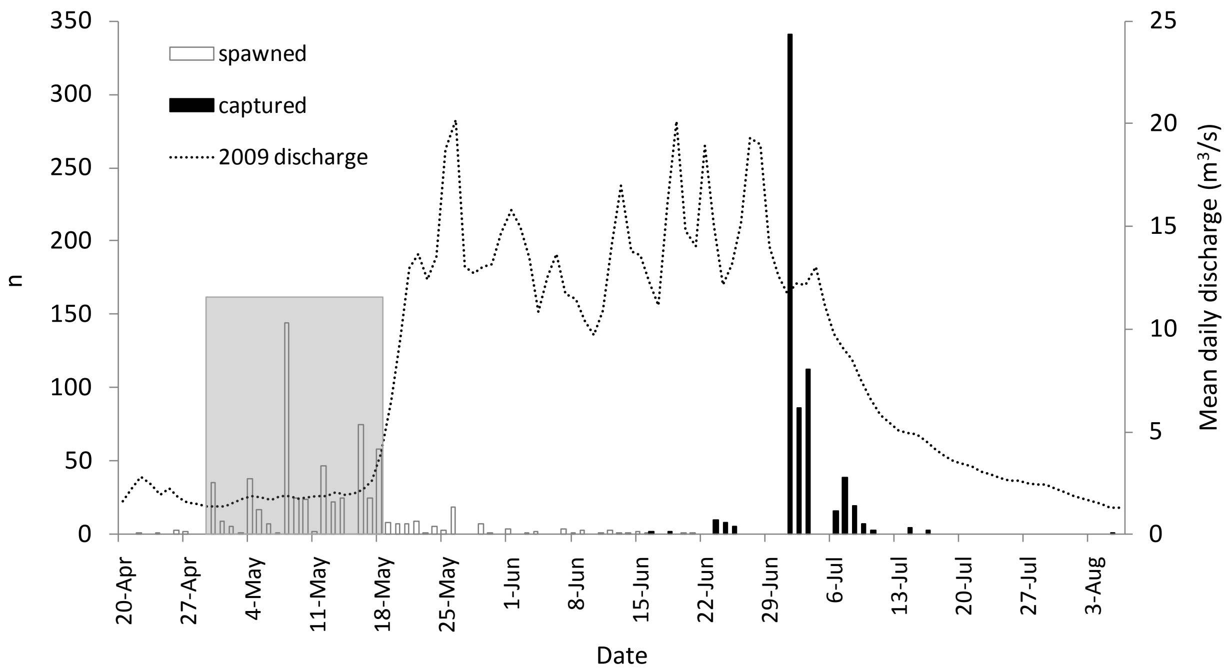

Figure 21. Numbers of flannelmouth suckers captured by drift net sampling per date, estimated dates they were spawned, and associated mean daily discharge (USGS gauging station 09213500) in the Big Sandy River, Wyoming, 2009. The gray shading represents estimated peak spawning period.

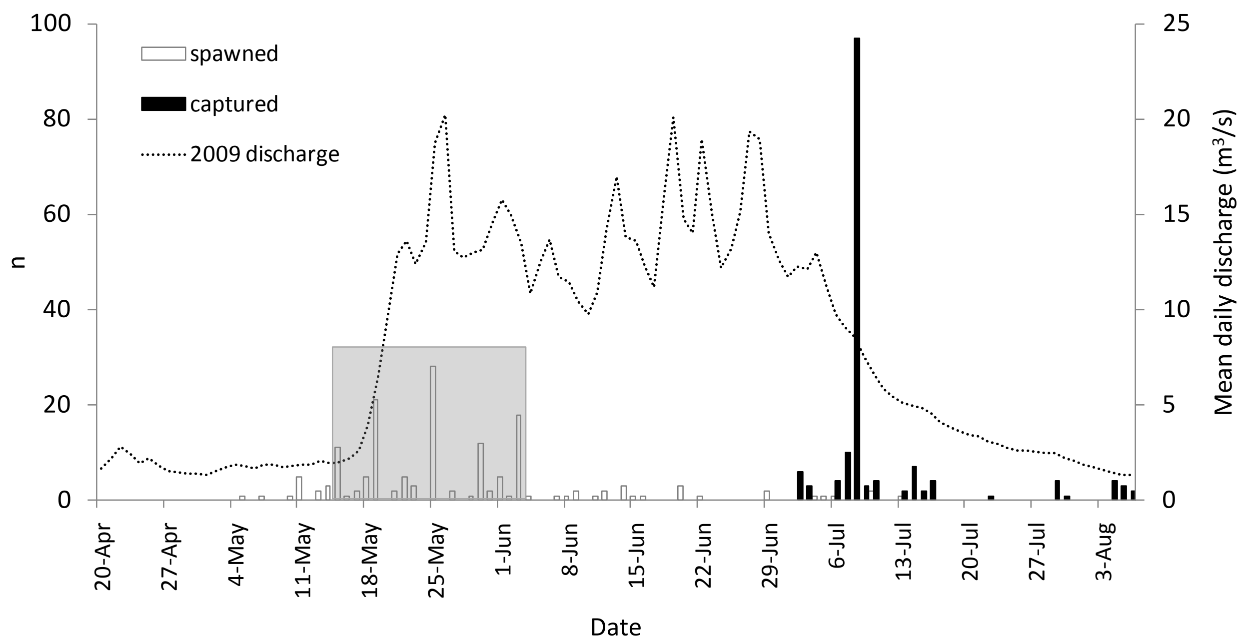

Figure 22. Numbers of bluehead suckers captured by drift net sampling per date, estimated dates they were spawned, and associated mean daily discharge (USGS gauging station 09213500) in the Big Sandy River, Wyoming, 2009. The gray shading represents estimated peak spawning period.

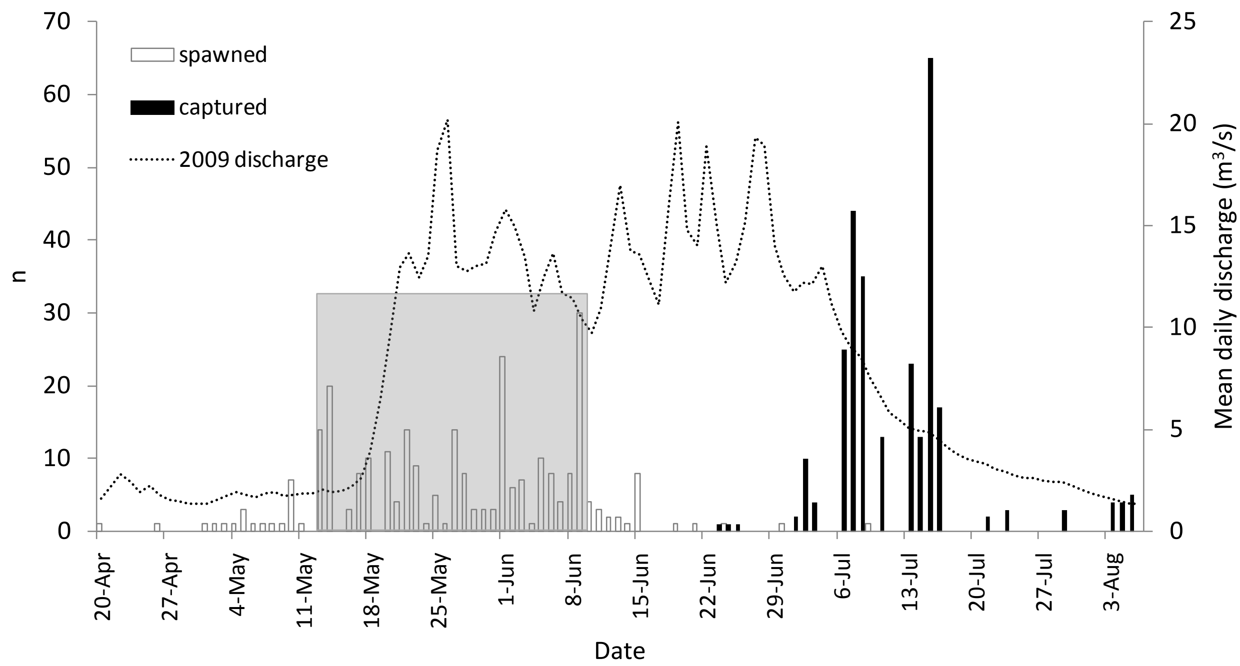

Figure 23. Numbers of white suckers captured by drift net sampling per date, estimated dates they were spawned, and associated mean daily discharge (USGS gauging station 09213500) in the Big Sandy River, Wyoming, 2009. The gray shading represents estimated peak spawning period.

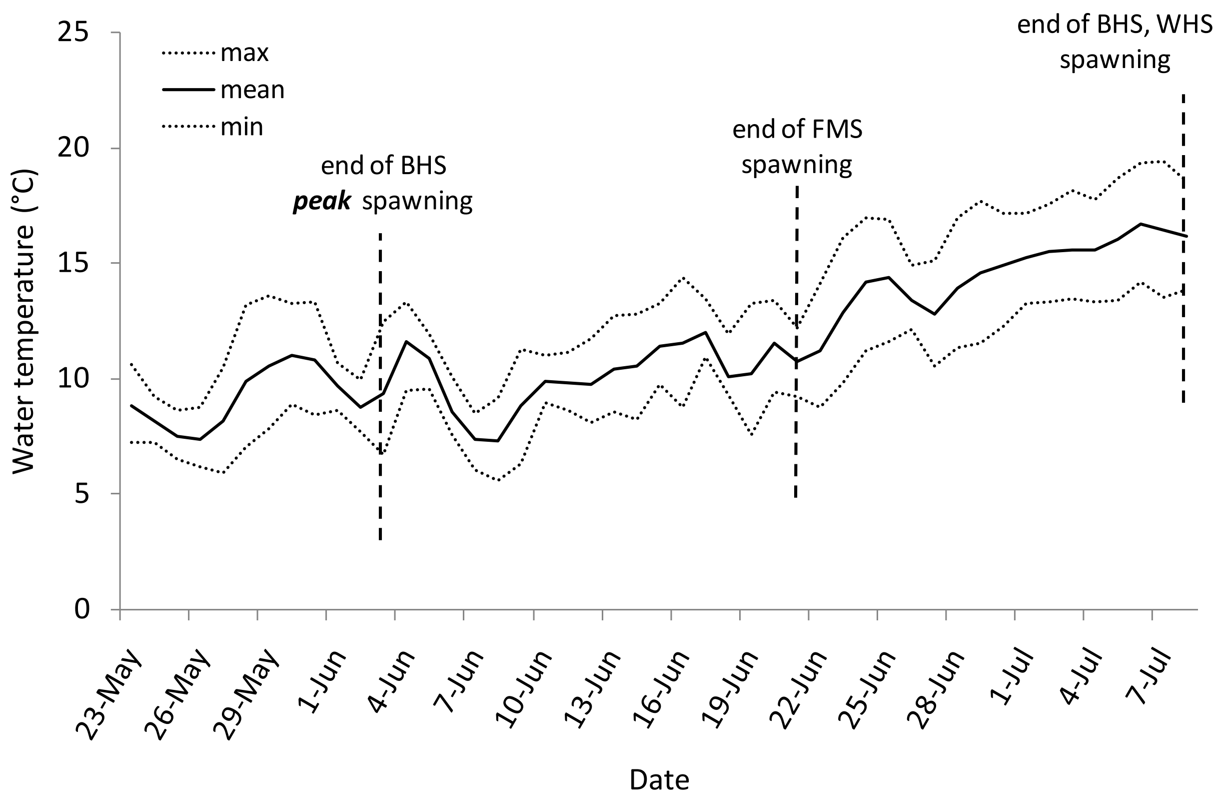

Figure 24. Mean, minimum, and maximum daily water temperatures from 23 May (date of first available temperature data) through end of bluehead sucker (BHS) peak spawning period and through dates of last spawned flannelmouth (FMS), bluehead (BHS), and white (WHS) suckers in the Big Sandy River, Wyoming, 2009. Temperatures were recorded by a thermograph located 29.7 km upstream of Big Sandy Reservoir.

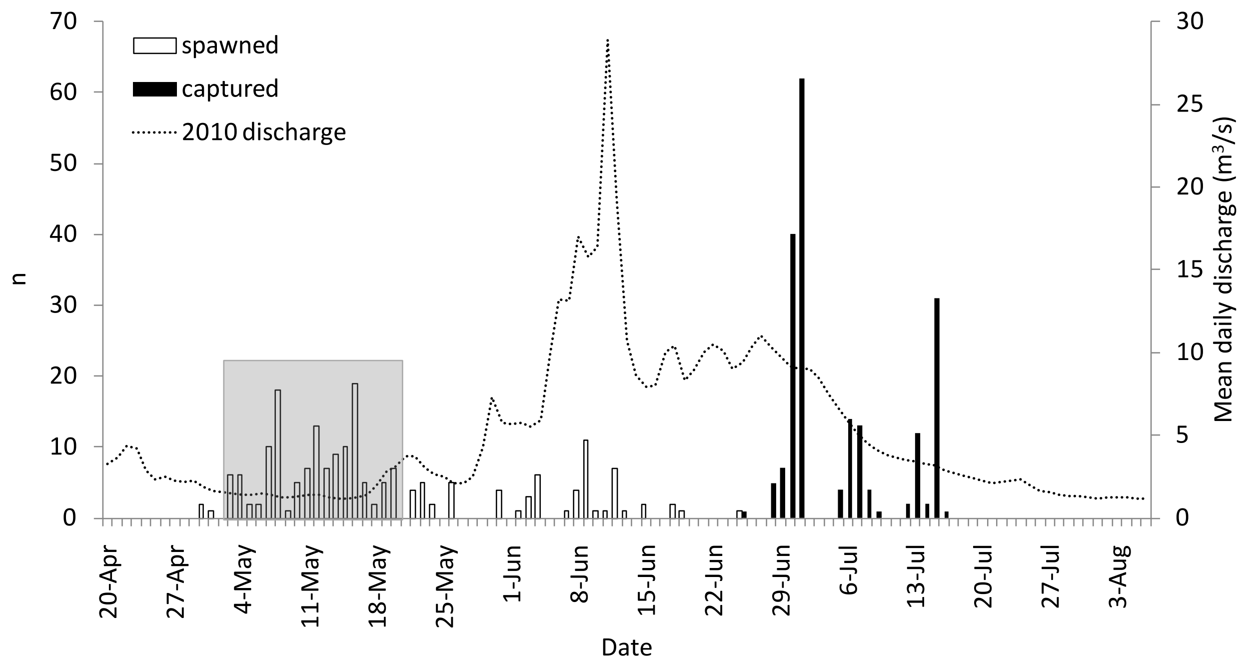

Figure 25. Numbers of flannelmouth suckers captured by drift net sampling per date, estimated dates they were spawned, and associated mean daily discharge (USGS gauging station 09213500) in the Big Sandy River, Wyoming, 2010. The gray shading represents estimated peak spawning period.

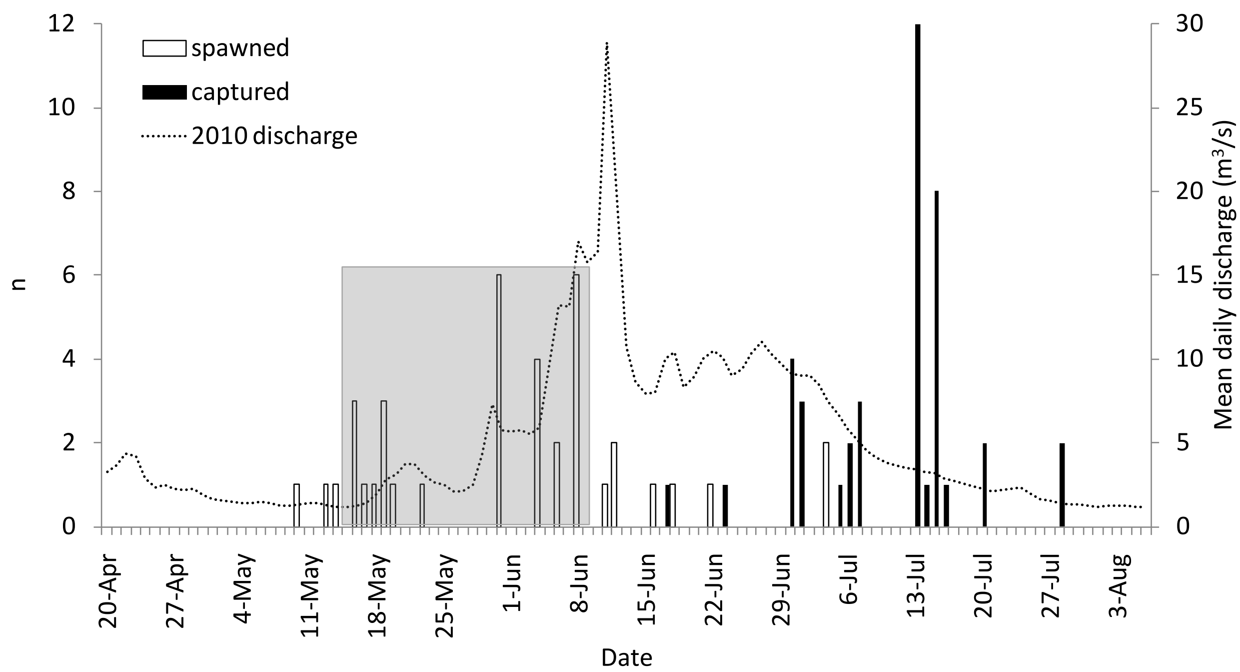

Figure 26. Numbers of bluehead suckers captured by drift net sampling per date, estimated dates they were spawned, and associated mean daily discharge (USGS gauging station 09213500) in the Big Sandy River, Wyoming, 2010. The gray shading represents estimated peak spawning period.

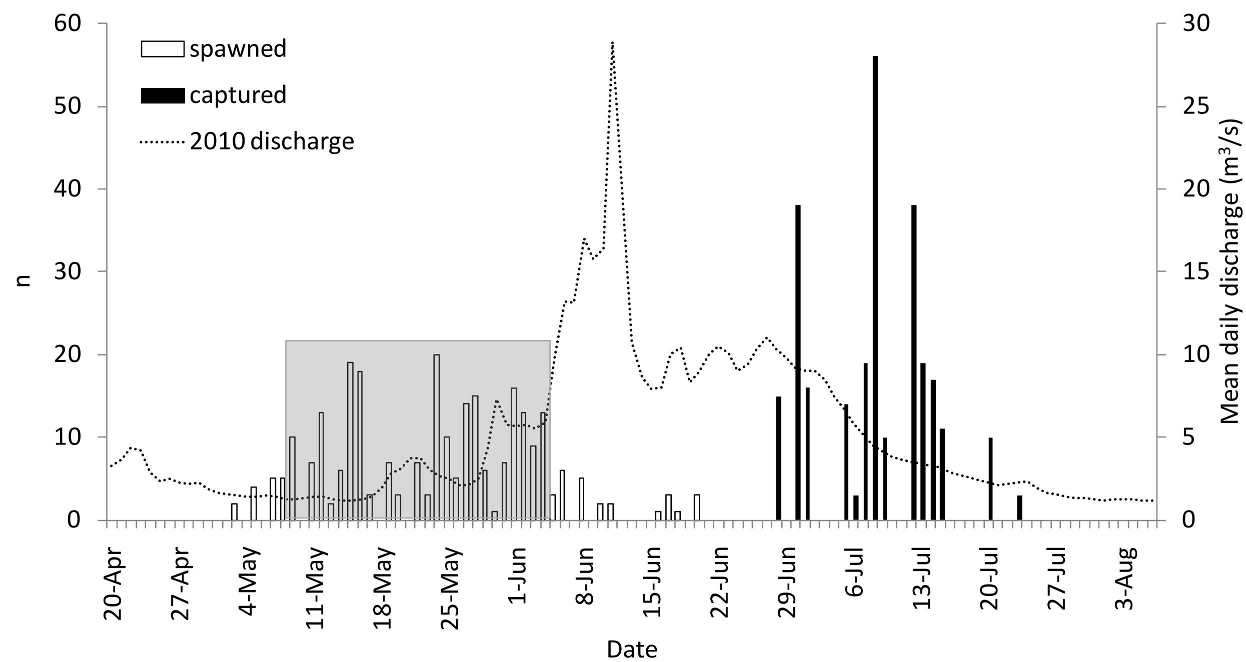

Figure 27. Numbers of white suckers captured by drift net sampling per date, estimated dates they were spawned, and associated mean daily discharge (USGS gauging station 09213500) in the Big Sandy River, Wyoming, 2010. The gray shading represents estimated peak spawning period.

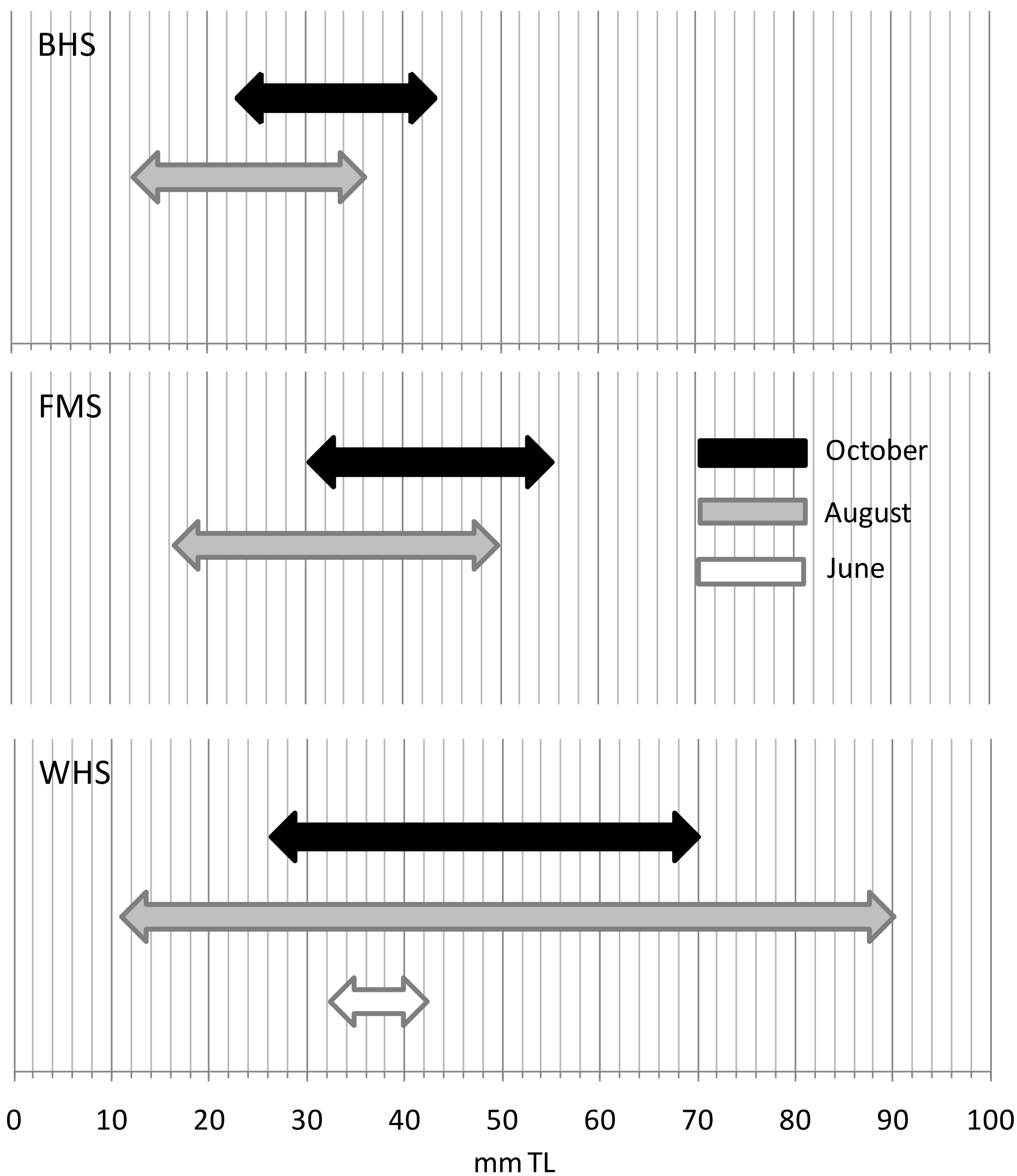

Figure 28. Total length (TL) ranges of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers captured in seine hauls in the Big Sandy River, Wyoming, during three time periods of 2009.

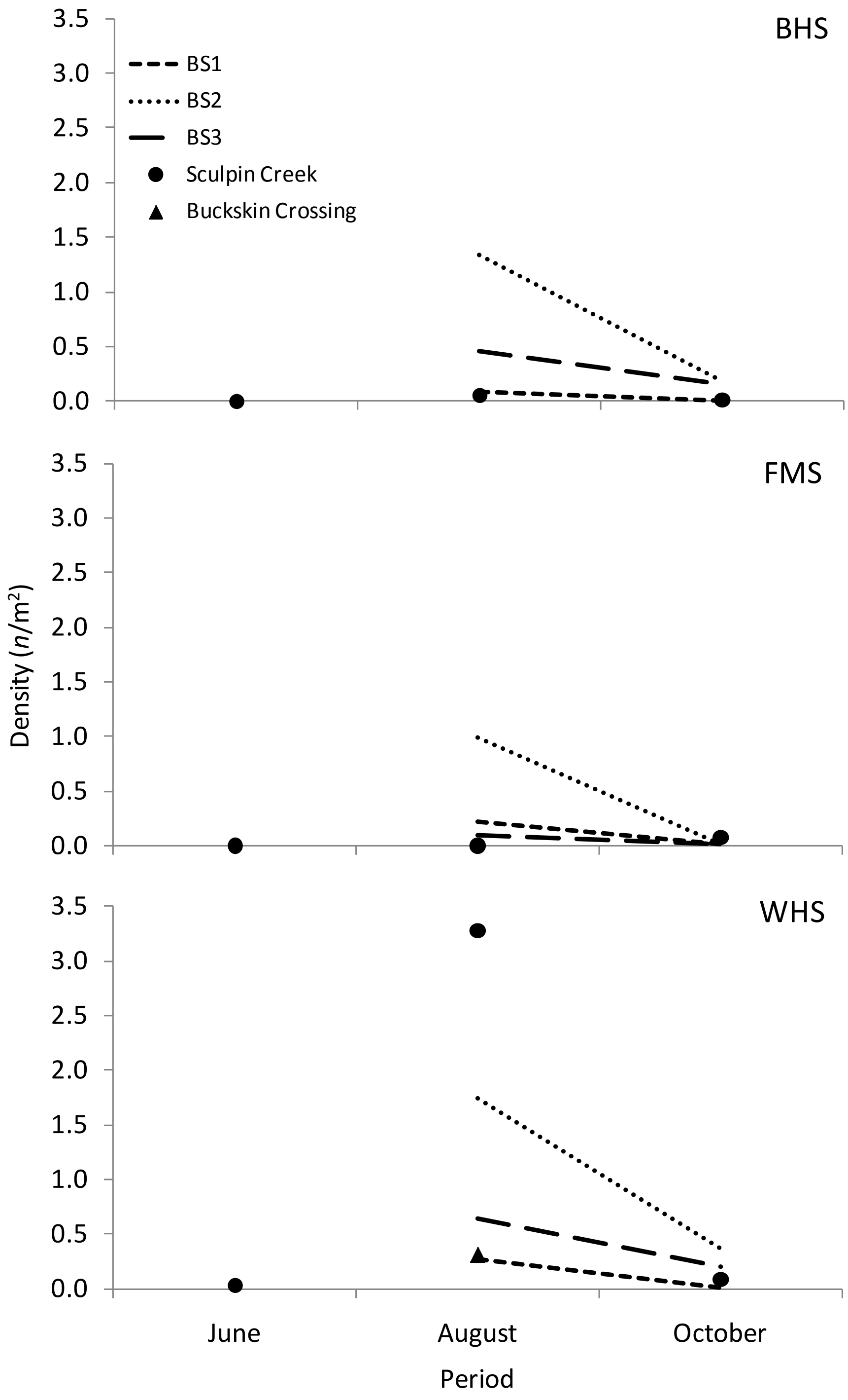

Figure 29. Densities of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers at seine locations in the Big Sandy River, Wyoming, during three time periods of 2009. BS1, BS2, BS3, and Buckskin Crossing are main channel locations approximately 4.0 km, 18.3 km, 45.2, and 86.6 km upstream of USGS gauging station 09213500, respectively. Sculpin Creek is a tributary located near Big Sandy River RK 45.3. Not all locations were sampled during each time period. No BHS or FMS were captured at Buckskin Crossing.

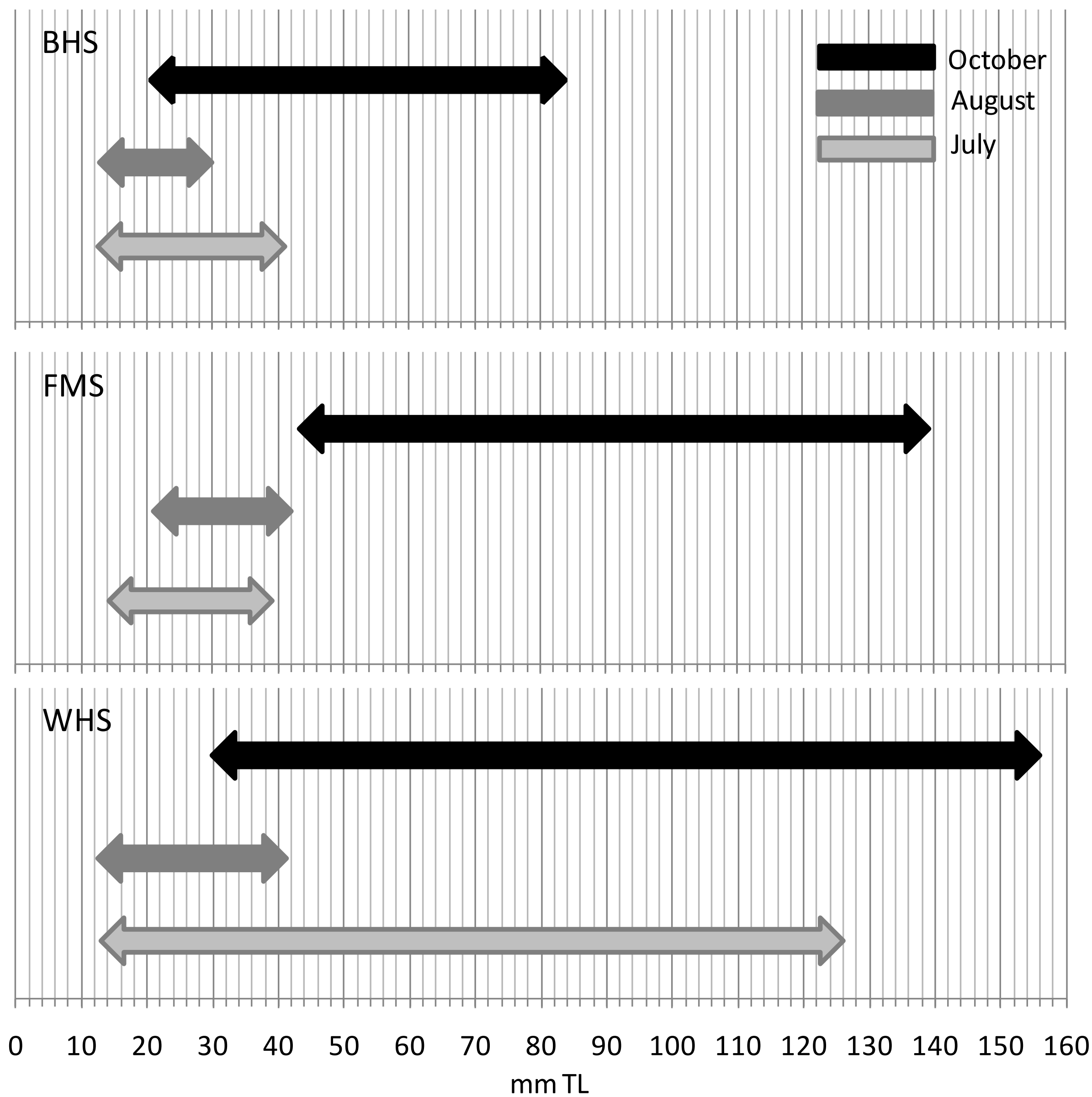

Figure 30. Total length (TL) ranges of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers captured in seine hauls in the Big Sandy River, Wyoming, during three time periods of 2010.

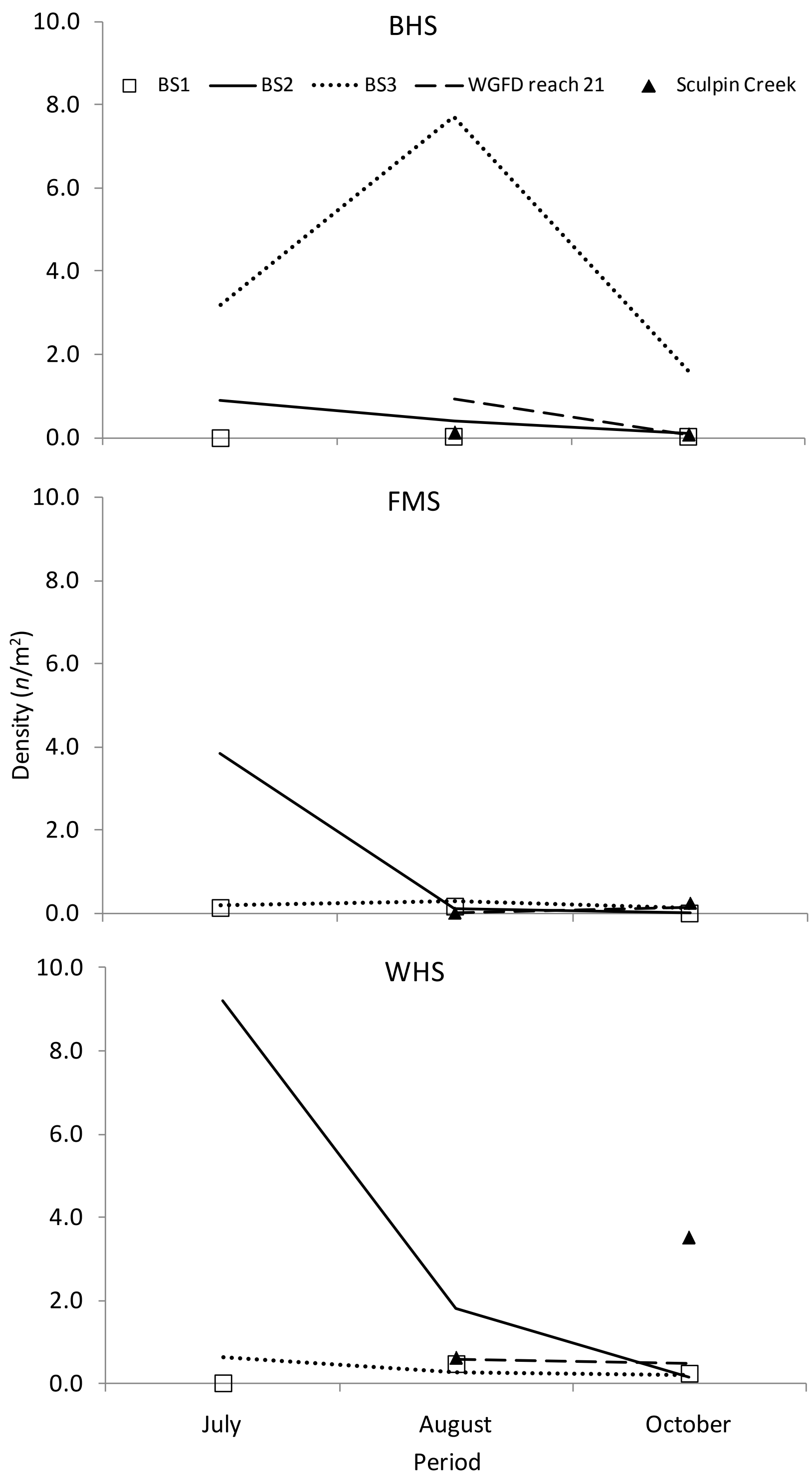

Figure 31. Densities of bluehead (BHS), flannelmouth (FMS), and white (WHS) suckers at seine locations in the Big Sandy River, Wyoming, during three time periods of 2010. BS1, BS2, BS3, and WGFD reach 21 are located at 4.0 km, 18.3 km, 45.2, and 63.3 km upstream of USGS gauging station 09213500, respectively. Sculpin Creek is a tributary located near RK 45.3. Not all locations were sampled during each time period.

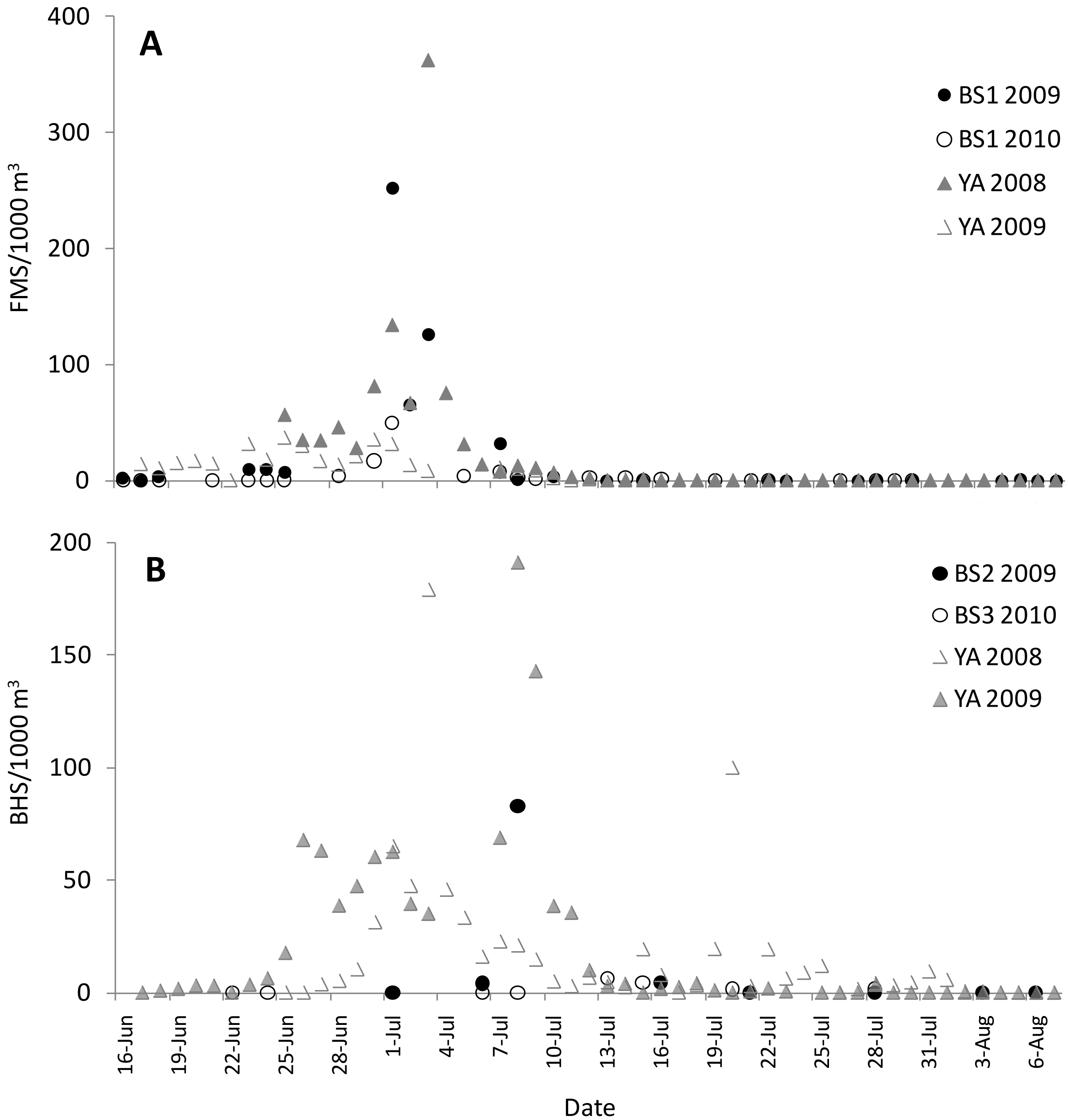

Figure 32. Densities of flannelmouth sucker (FMS, A) at drift net station BS1 and bluehead sucker (BHS, B) at drift net stations BS2 and BS3 in the Big Sandy River, Wyoming, 2009 and 2010, compared to a station in the Yampa River (YA), Colorado, 2008 and 2009. BS1, BS2, and BS3 are located approximately 4.0 km, 18.3, and 45.2 km upstream of USGS gauging station 09213500, respectively. YA is located approximately 1 km upstream of the confluence with the Green River in Dinosaur National Monument.