RELATIVE IMPORTANCE OF ENVIRONMENTAL VARIABLES FOR SPAWNING CUES AND TRIBUTARY USE BY AN ADFLUVIAL LAKE SUCKER

by

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ABSTRACT

Relative Importance of Environmental Variables for Spawning Cues and Tributary Use by an Adfluvial Lake Sucker

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The federally endangered June sucker (*Chasmistes liorus mictus*), which is endemic to Utah Lake, UT, historically spawned in all significant tributaries flowing into Utah Lake. However, due to a variety of anthropogenic changes, June sucker spawning is now primarily restricted to the Provo River, the largest tributary to Utah Lake. The purpose of this study was to gain a better understanding of the spawning and early life history of the June sucker. My specific objectives were to determine (1) what environmental factors attract or deter June suckers to certain Utah Lake tributaries for spawning; (2) what cues June suckers to migrate upstream to spawn; (3) if June suckers use more than one tributary for spawning; and (4) what limiting factors exist in these smaller tributaries. I performed weekly trap-netting surveys and installed passive integrated transponder tag interrogation systems into five Utah Lake tributaries during the spring of 2008 to determine if suckers were using multiple tributaries for spawning and to determine the timing and number of fish migrating upstream to spawn. I coupled the trap-netting data (staging) and migration data (tributary use) with a suite of biotic and abiotic environmental variables in a random forest model to establish the strongest relationships that exist between fish migration and environmental factors. I found that June sucker were present at the mouths of all tributaries sampled and migrated up three of the five tributaries during the spawning season. The Provo River was the tributary most used. Evidence of reproduction was found in four of the five tributaries by the presence of larval June sucker. The random forest model, for staging, indicated that lower total dissolved solids of the tributaries influenced higher catch per unit effort at the mouths of the tributaries, but explained only 33% of the variance. The random forest model, for tributary use, performed very well, explaining 85% of the variance and indicated discharge was the most important variable for upstream migration. Specifically, the ascending limb of the hydrograph appeared to cue migration and the descending limb cue spawning. I also found the most likely limiting factors in the smaller tributaries are degraded water quality and available spawning habitat. Results from this study show fish are selecting less degraded streams for spawning. Stream restoration projects, in the smaller tributaries, would likely increase the spawning habitat for June suckers and aid their recovery.

(60 pages)

PUBLIC ABSTRACT

Relative Importance of Environmental Variables for Spawning Cues and Tributary Use by an Adfluvial Lake Sucker

The endangered June sucker (*Chasmistes liorus mictus*), which is only found in Utah Lake, UT, historically spawned in all streams flowing into the lake, but due to human-caused changes their spawning is restricted to the Provo River. The purpose of this study was to gain a better understanding of the spawning and early life-history of the June sucker for recovery purposes.

My specific objectives were to determine:

1. what environmental factors attract or deter June suckers to certain Utah Lake tributaries for spawning,
2. what cues June suckers to migrate upstream to spawn,
3. if June suckers use more than one tributary for spawning,
4. what limiting factors exist in these smaller tributaries.

To accomplish this, I performed weekly trap-netting surveys and installed passive integrated transponder tag reader systems into five Utah Lake tributaries during the spring of 2008 to determine if suckers were using multiple streams for spawning and to determine the timing and number of fish migrating upstream to spawn. I coupled the trap-netting data and migration data with environmental data in a statistical model to establish the strongest relationships that exist between fish migration and environmental factors. I found that June suckers were present at the mouths of all tributaries sampled

and migrated up three of the five tributaries during the spawning season. The Provo River was the tributary most used. Evidence of reproduction was found in four of the five tributaries by the presence of larval June suckers.

One of my statistical models indicated that lower total dissolved solids of the tributaries influenced higher catch rates at the mouths of the tributaries. Another statistical model indicated discharge was the most important variable for upstream migration. Specifically, increasing flows appeared to cue migration and decreasing flows cued spawning. I also found the most likely limiting factors in the smaller tributaries are degraded water quality and lack of available spawning habitat. Streams that were most impacted (poor water quality and little or no spawning habitat) had no suckers present.

Results from this study show fish are selecting less degraded streams for spawning. Stream restoration projects, in the smaller tributaries, would likely increase the spawning habitat for June suckers and aid their recovery.

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INTRODUCTION

Freshwater ecosystems comprise one of the richest and most diverse biotic assemblages on the planet (Revenga and Mock 2000; Hermoso et al. 2009) and the fish that inhabit these ecosystems are the vertebrate taxa that are most responsible for this diversity (Saunders et al. 2002; Balian et al. 2008). Fishes, which account for over half of the 48,000 vertebrate species on the planet (Helfman et al. 1997; Nelson 2006; Olden et al. 2007) are also one of the most imperiled groups in the world today (Duncan and Lockwood 2001; Clark and May 2002; Humphries and Winemiller 2009). According to the American Fisheries Society Endangered Species Committee approximately 39% of described species in North America are considered imperiled, which consists of 700 freshwater and diadromous fish taxa (Jelk et al. 2008). That is a 92% increase from the 364 fish taxa listed in 1989 (Williams et al. 1989; Jelk et al. 2008). Of those 700 taxa, 230 are vulnerable, 190 are threatened, and 280 are endangered (Jelk et al. 2008). There are also 61 North American freshwater fish taxa that are presumed to be either extinct or extirpated from nature (Jelk et al. 2008).

Knowledge of the dynamics of fish populations is the key to understanding and developing management strategies for imperiled fish populations (Van Den Avyle and Hayward 1999). Population dynamics of commercially and/or recreationally exploited fishes are well studied and understood (Zipkin et al. 2008; Gurney et al. 2010; Gwinn and Allen 2010; Schopka et al. 2010), but information for nongame species, especially imperiled ones, can be scarce. The reasoning behind this scarcity is there are typically very little data that exists prior to a species listing and after they are listed, the number of individuals is so low, it can be difficult to obtain data (Gaston 1994; Warren and Burr 1994). By studying the population dynamics of imperiled fish populations, you gain a better understanding of how a population is persisting and can incorporate management objectives to help increase the population size.

There are three key factors that directly affect population dynamics of fishes: mortality, growth, and recruitment (Allen and Hightower 2010). When studying population dynamics of imperiled species, recruitment, which refers to young fish entering a population, is one of the most important parameters (Mangel et al. 2010). For a population to persist, it must have successful reoccurring spawning events so new recruits can enter the population and take the place of mortalities (Mangel et al. 2010). If a population does not have new recruits entering then deaths will out number births and the population will crash.

The June sucker, a lacustrine sucker endemic to Utah Lake, UT (Miller and Smith 1981; Sigler and Sigler 1987; Scoppettone and Vinyard. 1991), is a species where recruitment is a problem (Radant et al. 1987; Scoppettone and Vinyard. 1991). It was federally listed as endangered with the designation of critical habitat by the U.S. Fish and Wildlife Service (USFWS) on April 30, 1986 (Register 1986). The June sucker is a member to a group of suckers referred to as lakesuckers (Scoppettone and Vinyard. 1991). The other species of lakesuckers include, the thought to be extinct, Snake River sucker, *Chasmistes muriei*, from the Snake River, WY drainage; the short-nose sucker, *Chasmistes brevirostris*, and the Lost River sucker, *Deltises luxatus*, which inhabit lakes in the upper Klamath Basin, Oregon; and the cui-ui, *Chasmistes cujus*, which is restricted to Pyramid Lake, Nevada. Lakesuckers are unlike most catostomids; they have terminal to sub-terminal mouths used for pelagic planktivory, are long-lived (30-40+ years), large in size (500-1000 mm), are highly fecund (30,000-250,000 eggs) and reach sexual maturity between the ages of 4-12 years (Scoppettone and Vinyard. 1991; Cooke et al. 2005; Helfman 2007). These life-history strategies allows them to have intermittently successful reproduction when environmental conditions are favorable (Helfman 2007). Though their life history strategies permit them to deal with unfavorable spawning conditions they all are vulnerable to extinction.

The June sucker is a potamodromous species that exhibits a lacusrine-adfluvial migration life history (Northcote 1997). This type of life history spends a majority of their life in a lake system and then ascends inflow tributaries annually for spawning. June suckers spawn over gravel-cobble substrate in run-type habitat. Currently the June sucker is only known to spawn in the Provo River, the largest Utah Lake tributary, but it is thought that they historical spawned in other tributaries (Radant and Sakaguchi 1981). The June sucker was once the most abundant fish in the lake, numbering in the millions, (Jordan 1891), but surveys conducted in Utah Lake from the early 1950's until now have revealed a steady decline in the number of suckers caught (Radant and Sakaguchi 1981). In 1998 the wild population was estimated to only contain 300 individuals (Keleher et al. 1998). Many anthropogenic factors contributed to this population decline. Those factors include: water development, degraded water quality, urbanization, commercial harvesting during the spawning season, and nonnative introductions (Scoppettone and Vinyard. 1991; USFWS 1999).

Research conducted on the June sucker has involved propagation for population enhancement (Billman and Belk 2009), population dynamics of refugia stock (Billman and Crowl 2007), population monitoring (UDWR 2008), assessing the effect of nonnative species (Petersen 1996; Peterson 1996; SWCA 2002; Miller and Crowl 2006; SWCA 2006; Miller and Provenza 2007; Landom 2009), bioenergetics modeling (Boits 2005), spawning, larval drift, and emergence in the Provo River (Shirley 1983; Radant et al. 1987; Modde and Muirhead 1994), and movement of adult suckers (Buelow 2006). One of the recovery actions in the June Sucker Recovery Plan is to enhance the June sucker population in Utah Lake and its tributaries, specifically establishing other spawning stocks in one or more tributaries (USFWS 1999). Prior to this research, June suckers were known to spawn in only one tributary of Utah Lake, the Provo River (USFWS 1999). Since most biologists believe that June suckers only spawn in the Provo River, little work has been done in the smaller tributaries.

The purpose of this study is to gain a better understanding of the spawning and early life history of the June sucker. The primary objectives were to (1) determine what environmental factors attract or deter June suckers to certain Utah Lake tributaries for spawning; (2) determine what cues June suckers to migrate upstream to spawn; (3) determine if June suckers use more than one tributary for spawning; and (4) determine what limiting factors exist in these smaller tributaries. Results from this study can help gain a better understanding of what factors are limiting and what could be impeding the spawning of an imperiled migratory fish species. Therefore gaining this knowledge could help increase the number of spawning populations of this imperiled fish and aid in the recovery of an endangered species.

METHODS

Study Site

Utah Lake is a large, shallow lake located in Utah County in north central Utah. It is a remnant of prehistoric Lake Bonneville, which covered much of the state of Utah and parts of Nevada and Idaho, from 30,000 to 12,000 years ago. Utah Lake was formed when a natural dam at Red Rock Pass, ID was breached, causing a catastrophic flood (Bonneville Flood) due to the release of 4750 km^3 of water from Lake Bonneville into the Snake River which lasted for almost one year (Link et al. 1999). As a result, the level of Lake Bonneville dropped 105 m (Link et al. 1999). Over time, the level of Lake Bonneville continued to drop due to evaporation resulting in the formation of two lakes, which today are known as the Great Salt Lake and Utah Lake.

Utah Lake is one of the largest freshwater lakes west of the Mississippi River, spanning ~39,000 surface hectares. It has an average depth of 2.8 m and a maximum depth of 4.2 m at a full pool elevation of 1368 m (Fuhriman et al. 1981). It has a maximum width of 21 km and maximum length of 38 km (Radant and Sakaguchi 1981). Due to the large surface area to depth ratio and the high prevalence of wind the lake is almost always completely mixed and highly turbid (conductivity measurements of up to 1800 µS/cm have been recorded) due to high wave activity. Another cause of increased turbidity is the low amounts of aquatic vegetation from introduced common carp (*Cyprinus carpio*) (Brotherson 1981; Miller and Crowl 2006; SWCA 2006; Miller and Provenza 2007)

Utah Lake originally contained 13 native fish species including two endemic species, Utah Lake sculpin, *Cottus echinatus*, and June sucker. Due to anthropogenic changes, water quality degradation, and nonnative species introductions, the Utah Lake sculpin is extinct and the June sucker is endangered. The lake is now dominated by three nonnative species of fish: common carp, white bass, *Morone chrysops*, and black bullhead, *Amerius melas*. Only two native species remain, the Utah sucker, *Catostomus ardens*, and the June sucker.

There are five major and several smaller tributaries of Utah Lake. The major tributaries are the American Fork River, Battle Creek, Benjamin Slough, Provo River, Spring Creek, Hobble Creek, and Spanish Fork River. Historically, all of these tributaries provided excellent spawning habitat and were used by June suckers for spawning (Shirley 1983). However, anthropogenic changes such as channelization, water diversion and water storage changed the complex spawning and rearing habitats into more homogeneous simple habitats, which resulted in June sucker only using one tributary for spawning, the Provo River (USFWS 1999).

The American Fork River's headwaters are located on the east side of the Wasatch Mountains on Mount Timpanogos and Mount Baldy, and has a drainage area of approximately 132 km^2 (Stamp et al. 2002). The American Fork River upstream of the mouth of American Fork Canyon is a typical mid to high elevation river with substrate comprised of predominantly cobble and boulders and the habitat is drop pool. The portion of the river downstream of the canyon mouth contains numerous irrigation diversions, which can completely dewater the channel even in relatively wet years. The lower portion, near the lake interface, is severely channelized. This channelization has produced a plane bed morphology and little riparian vegetation. The average temperature for the lower American Fork River in the spring is 11.7 °C.

Battle Creek and Spring Creek are spring fed tributaries flowing into the northeast corner of Utah Lake. Battle Creek originates on the west side of Mount Timpanogos and Spring Creek flows from large springs located in Lehi, UT. The drainage area of these two tributaries is relatively smaller than other tributaries, less than 270 km^2 each. Due to their small size and spring-fed origins, their discharges are not as dynamic as other tributaries of Utah Lake. The springtime temperatures of Battle Creek and Spring Creek are higher than other tributaries, 13.02 and 15.57 °C, respectively. This increase in temperature is due to the lack of riparian areas because these tributaries flow through urban areas.

Benjamin Slough is a moderately sized tributary flowing into the southern end of Utah Lake near Lincoln Beach. It is formed from three separate creeks (Beer Creek, Spring Creek and Peteetneet Creek), which drain off the west side of Mount Nebo and through the agricultural lands of Utah Valley. A majority of Benjamin Slough is devoid of riparian vegetation because it flows through agricultural lands, except the lower two miles, which is part of the Utah Lake Wetland Preserve. The result of the lack of riparian vegetation is higher average spring temperatures, 16.69 °C. The substrate of the lower portion of Benjamin Slough is dominated by sand and silt, which are a result from the runoff from the agricultural fields.

The Provo River drains approximately 1735 km^2 and originates in the Uinta Mountains 80.5 km northeast of Provo, UT (Holden et al. 1994; Cook 2000). It was once a river dominated by spring runoff with several braided channels and a delta at its mouth. Now the Provo River has two reservoirs (Jordanelle and Deer Creek) located upstream of Utah Lake and flow in the lower section of the river is mostly dependent upon releases from Deer Creek Reservoir. The substrate of the lower Provo River is comprised mostly of gravel and cobble and the habitat is heterogeneous consisting of riffles, runs, and pools. The riparian area of the Provo River is dominated by Fremont cottonwoods (*Populus Fremontii*) and willows (*Salix spp.*). The JSRIP has an allotted amount of water that can be released from Deer Creek Reservoir each year for June sucker spawning.

Pre-Spawning Behavior

Prior to June sucker's upstream spawning migration; they congregate at the mouths of tributaries. I am referring to this congregating as pre-spawning (staging) behavior. During the spring and summer of 2008 June sucker staging behavior was monitored using trap-nets set at the mouths of the American Fork River, Battle Creek, Benjamin Slough, Provo River, and Spring Creek from 29 April – 18 June. Three to six trap-nets were set for approximately 24 hours each week at the mouths of each tributary. All tributary mouths were sampled at least once each week.

All suckers captured were immediately removed from the nets then placed in a holding pen. All nonnative fish species captured were counted then released. The data collected from the netting surveys was used to calculate catch per unit effort (CPUE) at each tributary mouth. In addition, suckers captured were measured for total length (mm), weight (g), sex, and reproductive condition (presence of milt or eggs). Fish were scanned for a Passive Integrated Transponder with a Destron Fearing Pocket Reader EX; if no PIT tag was present, one was injected ventrally just anterior of the left pelvic fin origin with a

Biomark MK 7 Implanter. If a PIT tag was present, the number was recorded. Only data from the 2008 sampling was used.

To quantify potential factors associated with sucker staging behavior, a suite of biotic and abiotic water parameters were measured throughout the spring and summer of 2008. Temperature loggers (HOBO temperature logger, UA-001-64) were placed at the mouth of each tributary and between 0.22 and 3 km up in each tributary to continuously log temperature data. Conductivity, total dissolved solids (TDS), temperature, pH, dissolved oxygen (DO), and salinity (water chemistry) were measured with an YSI Professional Plus multi-parameter meter in three locations of each tributary on a weekly basis from May-June (Table 1). One of the locations was in the tributary (where the temperature loggers were located) and the other two were collected at two different locations at each tributary's mouth; one on each side of the plume flowing into the lake (Figure 1). Water samples were collected, according to the protocol of the Aquatic Biochemistry Lab at Utah State University, simultaneously with the water chemistry via grab samples. These water samples were analyzed, by the Aquatic Biochemistry Lab, for dissolved organic carbon (DOC), total dissolved nitrogen (TDN) and total dissolved phosphorus (TDP). Discharge was measured in four of the five tributaries (American Fork River, Battle Creek, Benjamin Slough, and Spring Creek) with a Marsh-McBirney Flowmate Model 2000 flow meter on a weekly basis. Discharge was measured on a single transect in each tributary and was calculated using the methods stated in Gore 2006. Continuous discharge data for the Provo River was acquired through stream gage data from the Central Utah Water Conservancy District. These specific variables were chosen *a priori* based upon previous research that has shown they are linked to spawning cues (Huber and Bengston 1999; Heise et al. 2004; Durham and Wilde 2006; King et al. 2010). There has not been a lot research that has focused on environmental variables and spawning migration, so I chose to include all variables I found linked to spawning migrations.

Table 1. All predictor variable used in the random forest models.

Predictor Variable	**Median Value**	**Range of Values**
Day Length	14.8 hrs	13.8-15.03 hrs
Discharge	0.55 m^3s^{-1}	0-22 m^3s^{-1}
Temperature (Lake)	17.15° C	11.85-24.25° C
Temperature (Stream)	15.8° C	8.4-25.9° C
Dissolved Oxygen (Lake)	8.78 mgL^{-1}	4.955-15.45 mgL^{-1}
Dissolved Oxygen (Stream)	9.77 mgL^{-1}	4.99-12.21 mgL^{-1}
Total Dissolved Solids (Lake)	770.25 mgL^{-1}	477.75-1098.5 mgL^{-1}
Total Dissolved Solids (Stream)	422.5 mgL^{-1}	188.5-1550.5 mgL^{-1}
pH (Lake)	8.395	7.7-8.67
pH (Stream)	8.43	7.72-8.95
Dissolved Organic Carbon (Lake)	3.615 $mgCL^{-1}$	2.5598-5.936 $mgCL^{-1}$
Dissolved Organic Carbon (Stream)	2.51 $mgCL^{-1}$	1.192-9.2115 $mgCL^{-1}$
Total Dissolved Nitrogen (Lake)	0.7741 μgL^{-1}	0.3653-1.6352 μgL^{-1}
Total Dissolved Nitrogen (Stream)	1.4844 μgL^{-1}	0.2246-5.2719 μgL^{-1}
Total Dissolved Phosphorus (Lake)	0.05935 μgL^{-1}	0.0086-0.1636 μgL^{-1}
Total Dissolved Phosphorus (Stream)	0.0202 μgL^{-1}	0.003-0.377 μgL^{-1}

I used random forest models (Breiman 2001) to determine which independent variables best predicted staging behavior. Random forests was chosen over other statistical methods because of the ability to handle complex ecological data that typically has small samples sizes, a large independent to dependent variable ratio, exhibits multi-colinearity, and are unbalanced (De'ath and Fabricius 2000; Breiman 2001; Prasad et al. 2006; Cutler et al. 2007). Random forests compute a collection of numerous (500-2000) classification or regression trees, which are bootstrap samples of the original data (Prasad et al. 2006; Cutler et al. 2007). Data not included in the bootstrap samples

Figure 1. Provo River flowing into Utah Lake. The yellow dots indicate the sampling locations for water quality and chemistry taken on each side of the river plume. Photo courtesy of Google Earth.

("out-of-bag observations") were used to compute accuracies and error rates of the trees and are used essentially to cross-validate the random forests so they are not over-fit (Cutler et al. 2007). Measures of variable importance are also calculated based upon the "out-of-bag" observations. When each tree in the forest is constructed, there is a misclassification rate for each out-of-bag observation (Cutler et al. 2007). The variables are then randomly permuted and the modified out-of-bag observations are passed through the trees to get new predictions (Cutler et al. 2007). The measure of the importance of each variable is calculated by taking the difference between the original and modified misclassification rates, divided by the standard error (Cutler et al. 2007). The output for variable importance is a plot created by the random forest program, which rates variable importance based upon percent increase in mean square error. Partial dependence plots were generated to graphically characterize the marginal effect a predictor variable has on the response (Cutler et al. 2007).

I used the randomForest library (Liaw and Weiner 2002) in the R statistical package (Team 2009) to create all models, variable importance plots, and partial dependence plots. The percent of variance explained was also examined to explain the variation in the responses of interest (Liaw and Weiner 2002). The percent of variance explained is viewed as a pseudo r-square, which is an indication of model performance (Pang et al. 2006). I used variable importance plots to determine which variables most influenced the response variable (staging behavior). I employed a variable reduction technique where I chose the top five or six most important variables from the variable importance plots and then performed a random forest on those variables and reran the variable importance plots. Variables in the second variable importance plots that scored highest in the variable importance plots were plotted on partial dependency plots so the relationship between the individual predictor variable and the predicted probabilities could be characterized (Cutler et al. 2007).

Tributary Use

To assess the usage of tributaries, I constructed and installed Passive Integrated Transponder interrogation systems in the American Fork River, Battle Creek, Benjamin

Slough, Provo River and Spring Creek in April-May 2008. Antennae were placed approximately 0.8 km upstream of the tributaries' mouths except for the Provo River, which was placed 2.4 km upstream. Antennae were constructed in a similar manner as described in Zydlewski et al 2006. The interrogation systems in the American Fork River, Battle Creek, Benjamin Slough, and Spring Creek consisted of a Digital Angel FS 2001 FR ISO Reader (cheese-block) and a 1.524 m x .914 m custom built antenna set up in a "pass through" design (Figure 2) (Zydlewski et al. 2006). These tributaries do not often experience high enough flows to damage the antenna. Therefore, we installed "pass through" design antennae (Zydlewski et al. 2006; Connolly et al. 2008). The antennae were anchored in the center of each tributary via T-posts, hose clamps, and duck-billed anchors. To make sure all suckers moving upstream went over each antenna, a funnel was created with large plastic (polyethylene) mesh fencing (2.5 cm x 2 cm) attached to the sides of each antenna and stretched to shore in four locations. The mesh was secured to the substrate by placing numerous large rocks where the pieces of mesh overlapped at the bottom. These antennae were each powered by a deep cycle marine battery, which was changed weekly. Each interrogation system was tested and downloaded when the batteries were changed to ensure they were functioning properly and to verify that spawning movements were being recorded. Periodically, tags were manually passed through the areas to ensure recordings were accurate.

Figure 2. Photo of the “pass through” design interrogation system set up in Battle Creek. All interrogation systems were set up similar to this except the Provo River, which were anchored to the bottom on all four corners.

The Utah Division of Wildlife Resources (UDWR) constructed and installed the interrogation system in the Provo River. It consisted of a Digital Angel FS 1001M (multi-plexer) and four custom built 6.096 m x 1.219 m antennae set up in a “pass by” design (Connolly et al. 2008). The Provo River antennae are powered by two deep cycle batteries attached to a solar panel, which constantly charges the batteries. The data from the multi-plexer was acquired from the UDWR in fall 2008 after all suckers had migrated from the river to the lake.

The data collected from the PIT tag antennae arrays recorded the number of tagged suckers moving into the tributaries to spawn. This parameter is used as one of the two dependent variables in the models created.

To determine potential factors associated with suckers' tributary use, the same set of independent variables were used as described earlier for staging behavior. These data were also analyzed using random forest models to help determine what environmental factors might influence tributary use.

Larval Sucker Production

Presence of larval fish in a tributary signifies that conditions existed and spawning occurred. Therefore, larval fish presence was estimated in Battle Creek and Spring Creek in 2007 and in all five tributaries in 2008 using two different methods; drift netting and light trapping (Shirley 1983; Modde and Muirhead 1994; Robertson et al. 1998; Marchetti et al. 2004; Pierce et al. 2007). Three drift nets (WaterMark® Stream drift nets, 500 µ Nitex® mesh, mouth opening 27.94 cm x 46.99 cm) were deployed for 0.5 h between 0000 – 0300 h (D.E. Snyder, Colorado State University Larval Fish Laboratory personal communication) in each tributary weekly from 1 Jun – 5 July 2007 and 18 Jun – 17 July 2008. Nets were anchored with 1.27 cm diameter rebar in a transect across each tributary perpendicular to flow (Modde and Muirhead 1994). Depths and velocities were measured in front of each drift net at the beginning and end of each sampling period to estimate the volume sampled by each net (Modde and Muirhead 1994). All nets were thoroughly rinsed into sample jars, and samples were preserved with a 5% unbuffered formalin solution.

Five, quatrefoil light traps (Southern Concepts Inc., Birmingham, AL) (Floyd et al. 1984) were set in each tributary on a weekly basis from 1 Jun – 5 July 2007 and 18 June - 22 July 2008. The light traps were placed between the mouth of each tributary and the PIT tag antenna array. The assumption was made that larval fish would only be captured during low-light hours of the day (dusk to sunrise) due to the nocturnal nature of larval fish movement (Modde and Muirhead 1994) and their positive phototaxis (Kelso and Rutherford 1996). The traps were deployed shortly before sunset then retrieved just after sunrise. The time fished was calculated based upon day-length calculations from (http://aa.usno.navy.mil/data/docs/RS_OneYear.php). Once the total time fished was calculated then CPUE was calculated for each tributary. All larval fish collected were euthanized in a 10% Tricaine Methanesulfonate (Finquel, MS-222) solution and then preserved in a 5% unbuffered formalin solution.

All larval fish collected from light traps and drift nets were initially identified to family (Auer 1982; Snyder et al. 2005). Then all catostomids were identified to species (Snyder and Muth 1988; Snyder and Muth 2004). These data were used to look for evidence of spawning in the tributaries.

Tributary Spawning Habitat Surveys

Habitat surveys were conducted on all five tributaries during the summer of 2008 to identify the presence of quality June Sucker spawning habitat. June sucker do not necessarily spawn in certain habitat types (i.e. riffles, runs, or pools), but quality June sucker spawning habitat consists predominantly of course gravel and small cobble substrate (50 to 120 mm in diameter), depths ranging from 0.3 m to 0.55 m, and mean channel velocities of 0.23 and 0.69 m/s (Shirley 1983; Radant et al. 1987). Prior to this study, June sucker spawning had only been documented in the Provo River.

Spawning habitat was measured via transects conducted at one reach in each tributary. Each reach was located just upstream of each antenna and downstream of migration barriers. Reach length was estimated based on 20 times the average stream width (Fitzpatrick et al. 1998). Within each reach, measurements were taken on 10 transects except for the Provo River. Sixteen transects were collected within the Provo River because it is much wider than the other tributaries. Habitat measurements were taken at 10 points equidistant apart within each transect. These measurements included: bank-full width, bank-full depth (water depth during spawning period), actual water depth, water velocity, and classified substrate type (e.g., 60% cobble, 40% gravel) (Kaufmann et al. 1999; Heitke et al. 2006). Since quality spawning habitat for June sucker consists of gravel and cobble, these two substrate types were grouped together for the analysis and are referred to as spawning substrate.

Radant (1987) described the three most important habitat variables for June sucker spawning to be substrate, velocity, and water depth. To determine if adequate spawning habitat was present in the smaller tributaries, I compared two of the three most important habitat measurements (bank-full depth and spawning substrate) of the four smaller tributaries with that of the Provo River. Velocity was not incorporated into this analysis because a good representation of stream velocities was not measured during the spawning period. I ran a one-way Analysis of Variance (ANOVA) using PROC GLM in SAS version 9.2 (SAS 2008). The response variables were spawning substrate and bankfull depth with tributary as the main effect. Significance was established at $P \leq 0.05$

in all analyses where applicable. All assumptions were met for the data except for the spawning substrate data. The spawning substrate data is in percentages, so to normalize the data, I added 0.001 and then arcsine-square root transformed the observations.

RESULTS

Pre-Spawn Behavior

A total of 27 net sets occurred at the mouths of each of the five tributaries. June suckers were captured at the mouths of all tributaries sampled during the pre-spawning period (Figure 3). The June suckers captured at the mouth of Benjamin Slough were immature and did not exhibit physical evidence of sexual maturity. Overall, a total of 135 June suckers were captured. The Provo River had the highest number of June sucker captures (Figure 3). There was one mortality at the mouth of the American Fork River. Thirty-six percent of the June suckers captured did not have a PIT tag. The ratio of males to females was approximately 0.84:1. I also captured 16 immature June suckers. All immature June suckers captured were a product of the hatchery program.

The random forest model predicting staging behavior performed rather poorly, explaining only 33% of the variance. Variable importance plots were created, first to reduce the number of independent variables and second to choose the variable that explains the most variance in staging behavior. The eight most important variables for the staging behavior model were chosen from the first variable importance plot. I then re-ran the variable importance plot with those eight variables (Figure 4). In the second variable importance plot the most important variable for predicting a higher CPUE for staging behavior was TDS at the stream/lake interface (Figure 5).

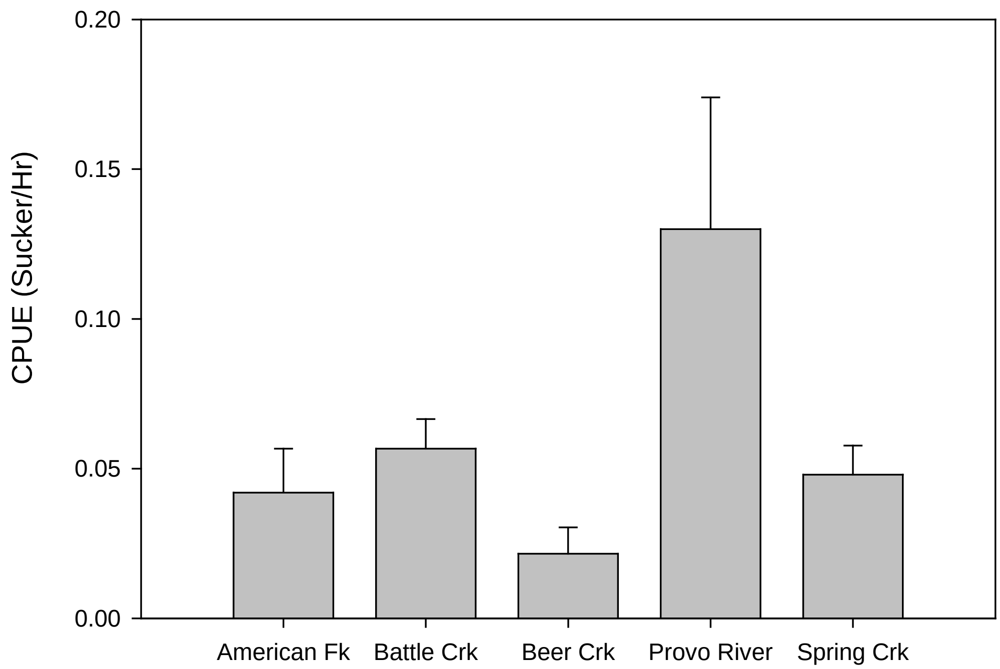

Figure 3. Number of June suckers captured per trap net hour (+SE) at the mouths of each tributary in spring 2008.

Results from the partial dependency plot show that nonlinear relationships exist between the variables from the second variable importance plots and CPUE. There is an inverse relationship between TDS at the stream and lake interface and CPUE. As TDS at the tributary mouths increase, CPUE decreases slightly (Figure 6). There is also a TDS threshold of approximately 625 mgL^{-1}. When TDS rises above 625 mgL^{-1}, CPUE drops.

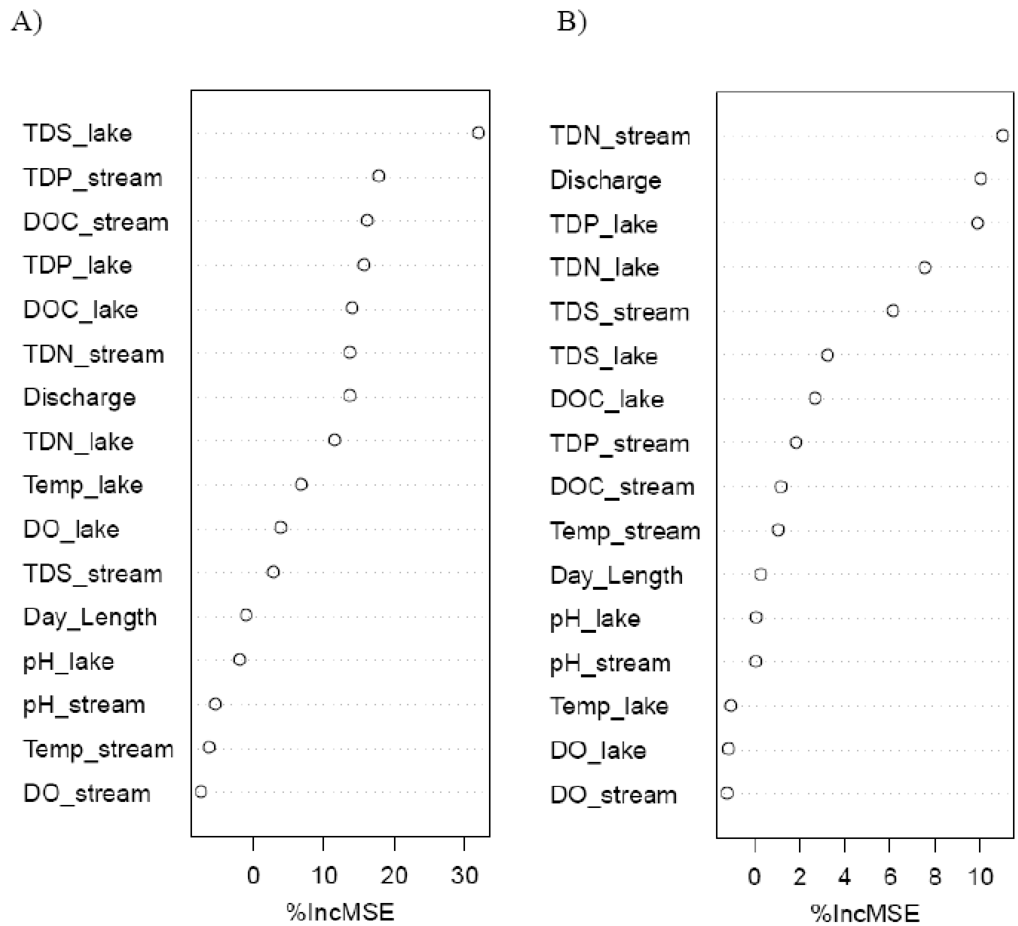

Figure 4. Variable importance plots for the two models A) staging and B) spawning with all predictor variables. TDS is total dissolved solids, TDN is total dissolved nitrogen, TDP is total dissolved phosphorus, DOC is dissolved organic carbon, and DO is dissolved oxygen. The x-axis is percent increase in mean squared error.

An ANOVA was performed to determine if TDS differed at the tributary mouths. The data met all of the assumptions of ANOVA and significance was established at $P \leq 0.05$. The American Fork and Provo Rivers both had significantly lower TDS (ANOVA: F=8.48; df=4, 22; P = 0.0003) than the other three tributaries (Figure 7).

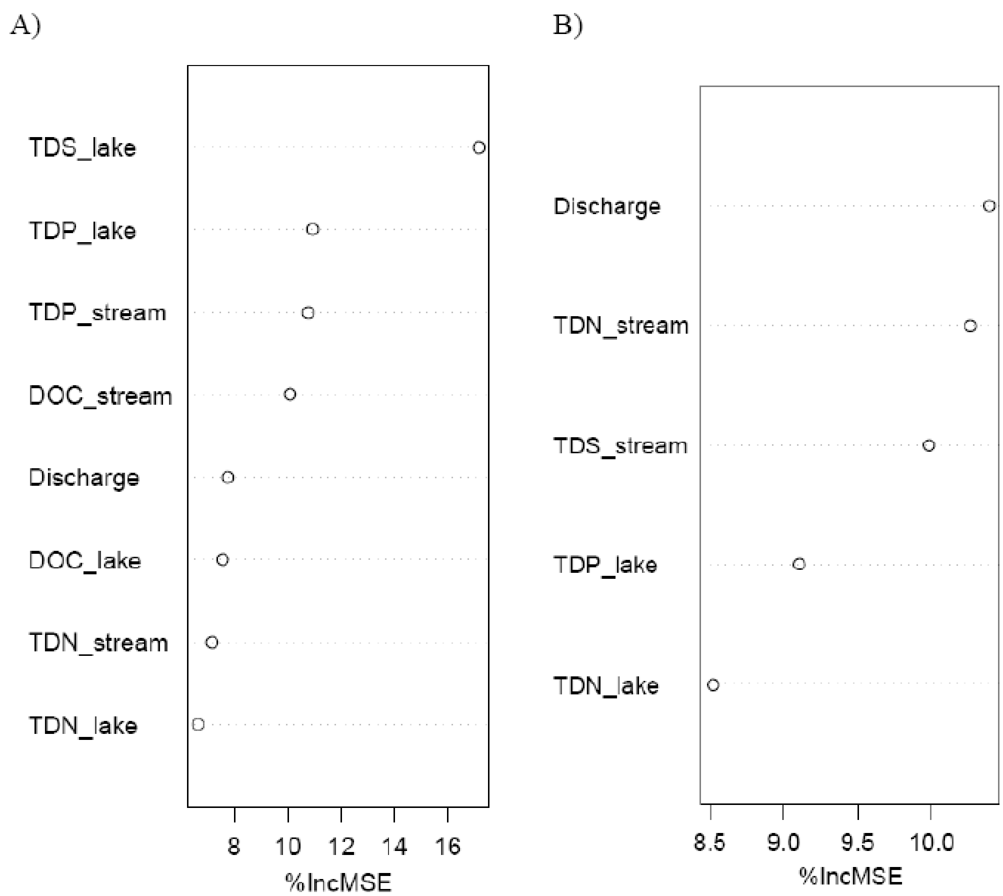

Figure 5. Variable importance plots for the two models A) staging and B) spawning with a reduced number of predictor variables. TDS is total dissolved solids, TDN is total dissolved nitrogen, TDP is total dissolved phosphorus, and DOC is dissolved organic carbon. The x-axis is percent increase in mean squared error.

Tributary Use

Antennae were successfully installed into all of the tributaries, but problems were encountered with three of the four antennae. The antenna in Battle Creek was first washed out and reinstalled in another area upstream. The reinstalled antenna was then replaced due to damage. The antenna in the American Fork River was completely washed out and destroyed by high flows. No replacement antennae were available, so I

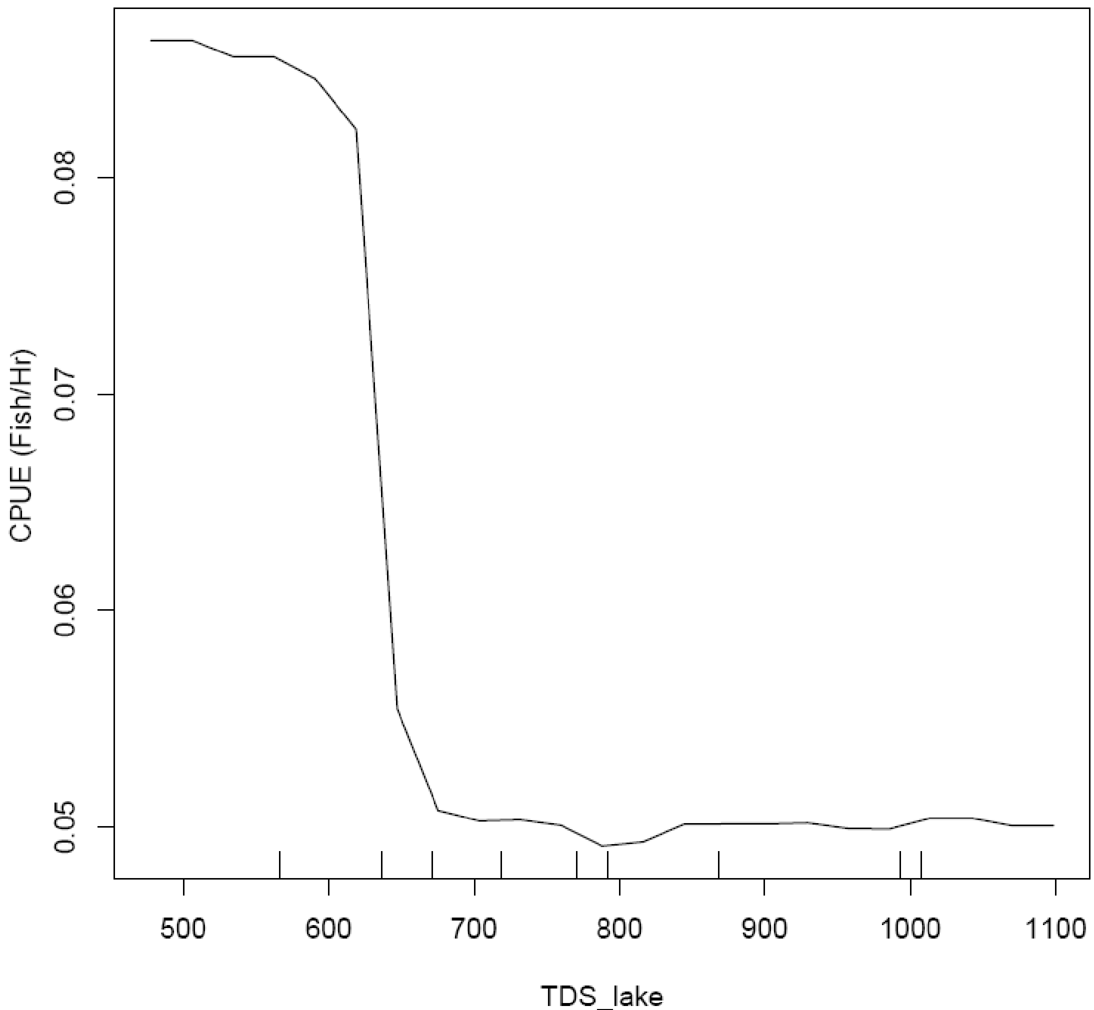

Figure 6. Partial dependence plot showing the effect of total dissolved solids, measured at the tributary's mouths, on the probability of getting a higher catch per unit effort at the mouths of the tributaries.

did not obtain any spawning movement data. Tributary use for spawning in the American Fork River would be extremely difficult due to the intermittent flow that occurs from irrigation withdraws. The antenna in Benjamin Slough was also washed out, but this occurred after June sucker were detected in the other tributaries. A total of 21

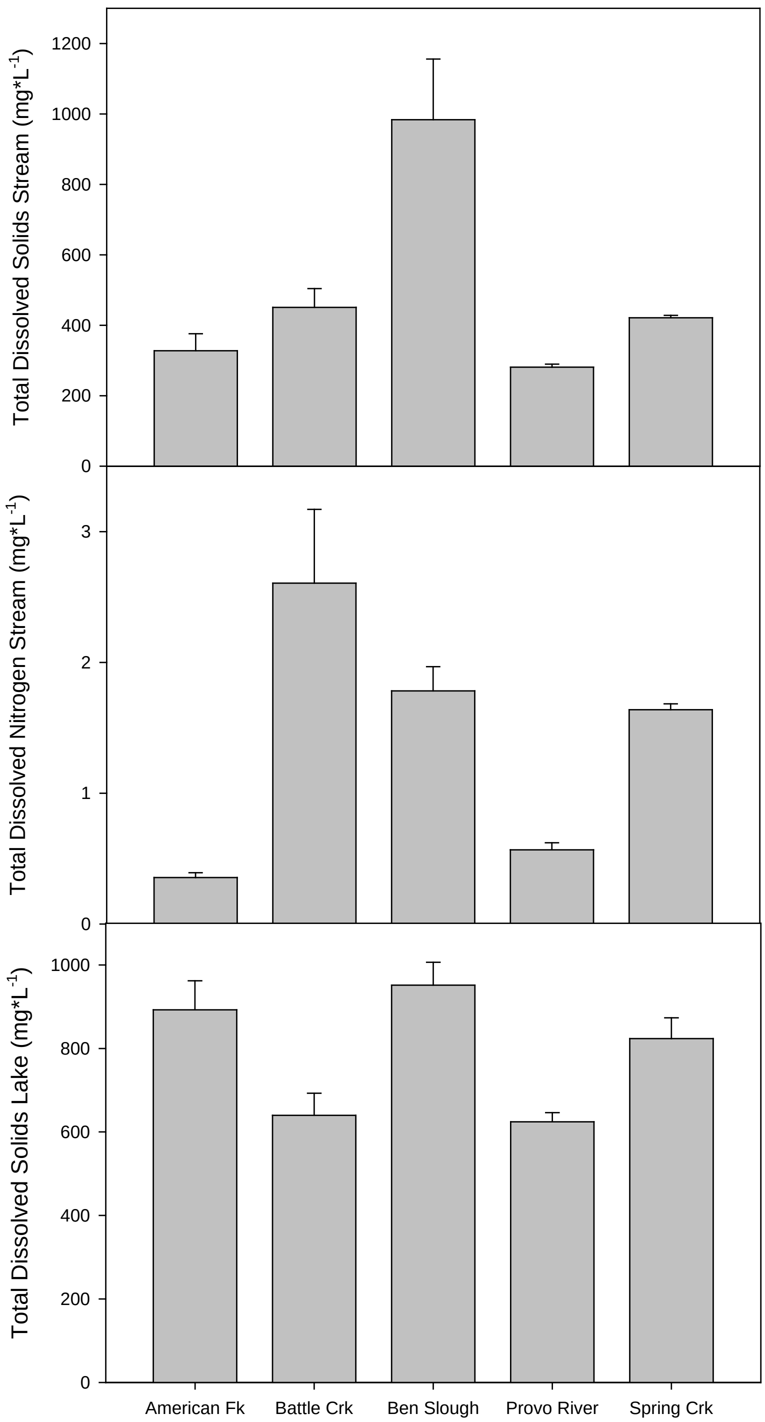

Figure 7. Histograms showing differences in the most important variables between the tributaries.

sampling events (number of unique PIT tag hits/week/tributary) occurred for this part of the study because I excluded the American Fork River.

Lake suckers (June and/or Utah) were detected in three of the five tributaries (Table 2). June suckers were detected in two of the five tributaries (Battle Creek and Provo River). The Provo River had the most total detections and most fish detected (Table 2). Fish began moving up the Provo River on 20 April 2008 and movement stopped, 1 September 2008. The first PIT tag detection in Battle Creek occurred on 30 May 2008 and the last was on 2 June 2008. The first Pit tag detection in Spring Creek occurred on 25 May 2008 and the last was 29 May 2008. No fish were detected in Benjamin Slough during the duration of sampling. The American Fork River antenna washed out.

Table 2. The number of total and unique PIT tag hits in each tributary from May 5, 2008-June 20, 2008. NA is not applicable because the antenna was destroyed.

Tributary	**Total Hits**	**Unique Hits**
American Fork	NA	NA
Battle Creek	142	4
Benjamin Slough	0	0
Provo River	2435	830
Spring Creek	6	2

The model predicting tributary use for spawning performed very well, explaining 85% of the variance. From the first variable-importance plots created, the five most important variables for the tributary use model were chosen and rerun for the variable reduction (Figure 4). In the second variable importance plots the most important variables for predicting tributary use for spawning was discharge, followed by TDN and TDS in the stream (Figure 5).

Discharge was the most important variable in the tributary use model. As discharge increases there is a rise in the number of fish that are detected by the PIT tag antennae, then detections gradually decrease as discharge increases (Figure 8). The results from the partial dependence plot warranted further investigation to characterize the relationship between discharge and fish moving into the tributaries. The Provo River was the only tributary in the study that had continuous discharge and PIT tag antenna data. When observing this data over a temporal scale a pattern emerges with discharge and antennae hits (Figure 9). Fish begin gradually moving into the Provo River as discharge increases. After the peak, discharge subsides and the number of individual fish hits detected doubles. Then as flow increases again, the number of hits detections drops two-fold.

The second most important variable in the tributary-use model was TDN in the stream. There is an inverse relationship associated with TDN of the streams and unique fish detections. As TDN in the streams increases, the numbers of detections drop from approximately 60 to 30 (Figure 10). There is a threshold of just over 1 μgL^{-1} of TDN. An ANOVA was used to determine if there were differences in TDN in the tributaries. TDN in the American Fork and Provo Rivers was significantly lower (ANOVA: F = 10.27; df = 4, 22; $P < 0.0001$) than in the other three tributaries (Figure 7).

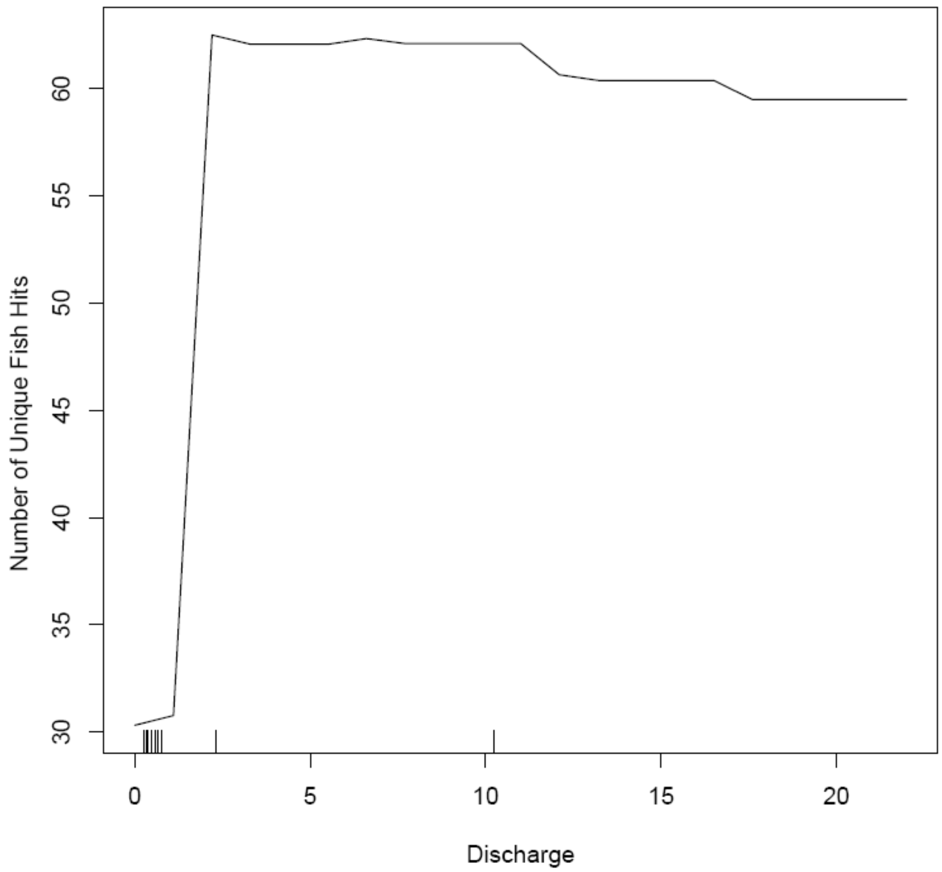

Figure 8. Partial dependence plot showing the effect of stream discharge on the probability of getting a higher catch per unit effort at the mouths of the tributaries.

The same inverse relationship occurs with TDS in the tributaries and antenna detections. As TDS increases the number of unique fish hits decreases (Figure 11). The threshold of TDS in the tributaries is approximately 400 mgL^{-1}. An ANOVA was performed to determine if TDS was different in the tributaries. The data met all of the assumptions and significance was established at $P \leq 0.05$. There were significant differences (ANOVA: $F = 12.67$; $df = 4, 22$; $P < 0.0001$) in TDS measured in each tributary. Benjamin Slough had much higher TDS than the other four tributaries.

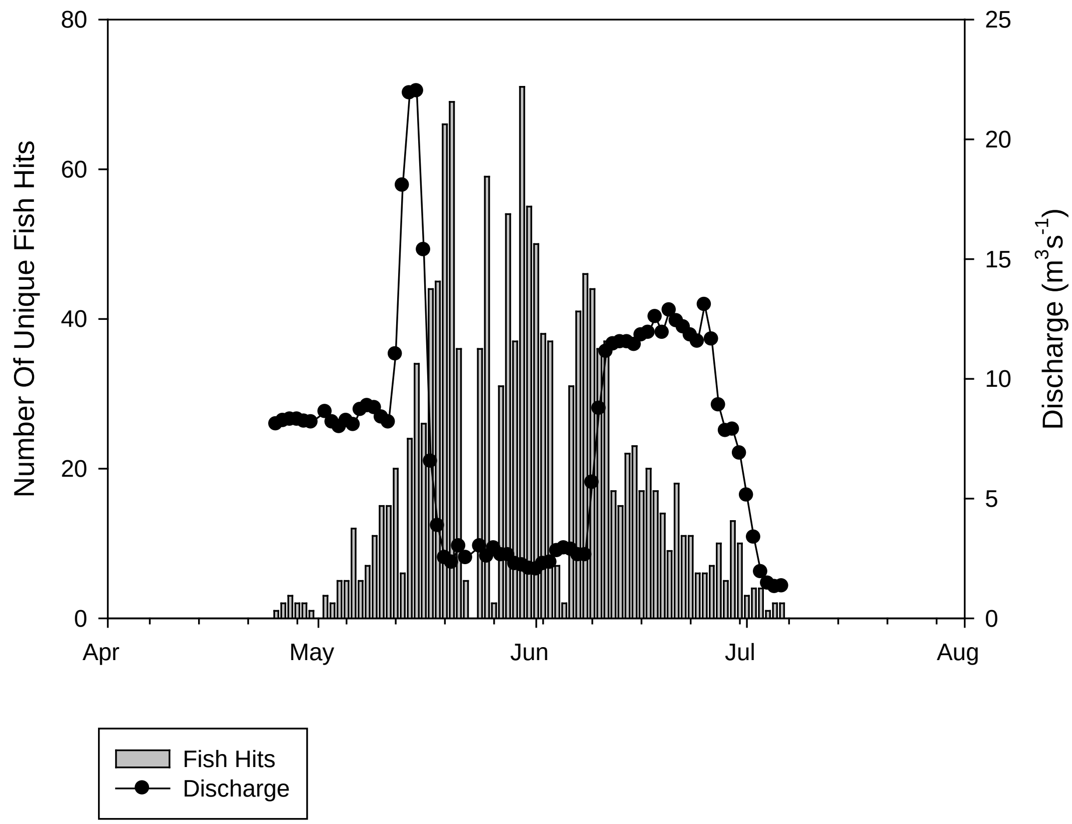

Figure 9. Number of individual June sucker PIT tag hits on the Provo River interrogation system. Scatter and line plot is the mean daily discharge of the Provo River at the USGS gauge 10163000 at Provo, UT. June sucker data provided by Utah Division of Wildlife Resources and discharge data from Central Utah Water Conservancy District.

Total dissolved solids were lowest in the Provo River, but not much lower than the other three tributaries (American Fork, Battle Creek, and Spring Creek (Figure 7).

Larval Fish Production

Larval fish were collected in all tributaries sampled in 2007 and 2008 (Tables 3). Larval suckers were captured in Battle Creek and Spring Creek in 2007, and the American Fork River, Battle Creek, Provo River, and Spring Creek in 2008 (Table 3).

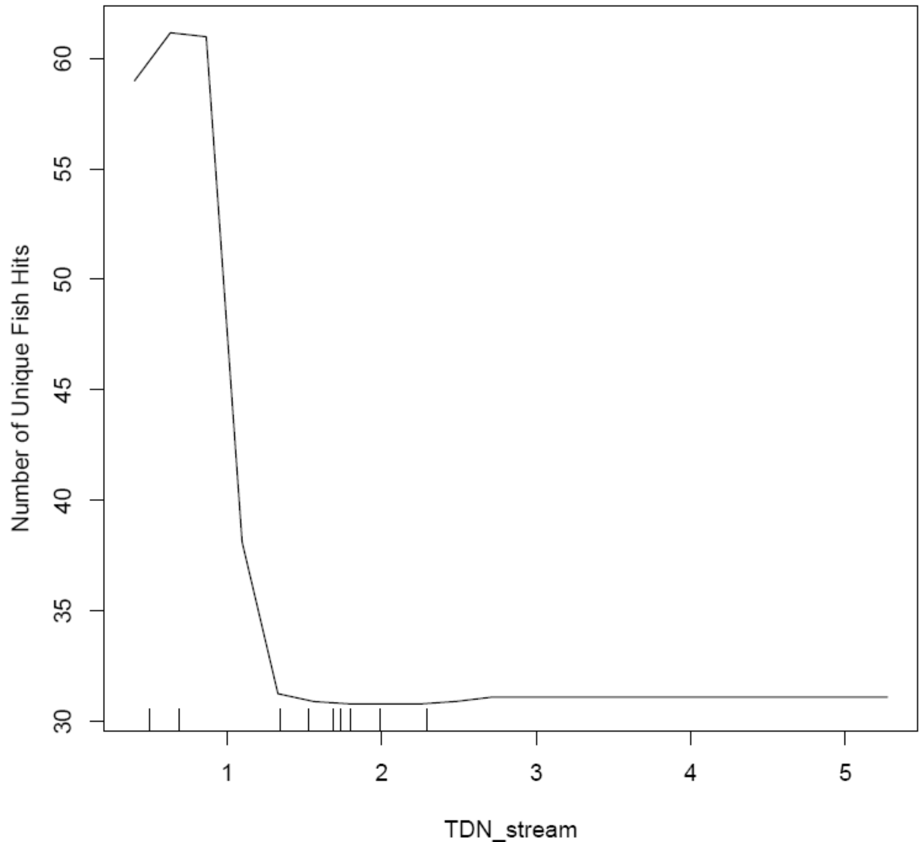

Figure 10. Partial dependence plot showing the effect of total dissolved nitrogen, measured in the tributaries, on the probability of getting a higher catch per unit effort at the mouths of the tributaries.

June sucker larvae were collected in Battle Creek in both drift nets and light traps in 2007 (Table 3). Larval June suckers were collected in the American Fork River, Battle Creek, Provo River, and Spring Creek in 2008 (Table 3). Larval June suckers were found in drift samples in Battle Creek, Provo River, and Spring Creek and in light traps in the American Fork and Provo Rivers and Spring Creek in 2008. The other catostomid species that was present in the larval fish sampling was the Utah sucker.

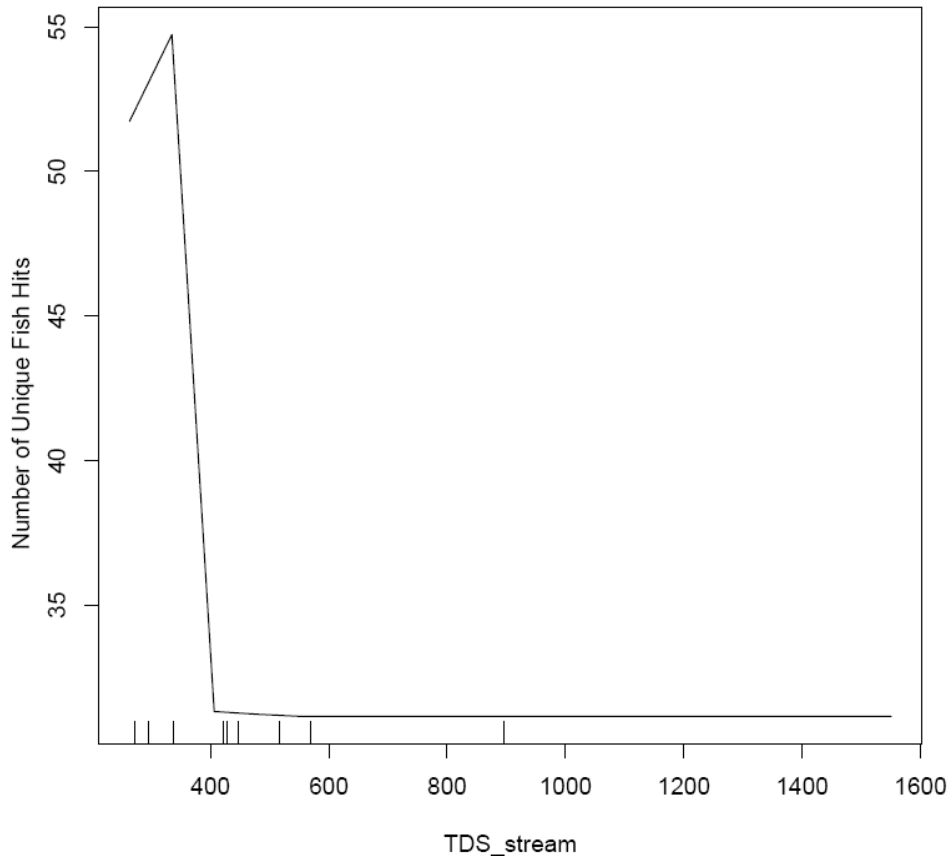

Figure 11. Partial dependence plot showing the effect of total dissolved solids in the stream on the probability of getting a higher catch per unit effort at the mouths of the tributaries.

Table 3. Numbers of larval fish caught in each tributary in light traps and drift nets in 2007 and 2008.

	Catostomidae	***Catostomus ardens***		***Chasmistes liorus***		**Other Species**	
		Drift	Light Traps	Drift	Light Traps	Drift	Light Traps
			2007				
Battle Creek	35	5	0	1	1	16	70
Spring Creek	0	1	0	0	0	40	164
			2008				
American Fork	0	7	0	0	1	0	0
Battle Creek	0	0	0	4	0	526	322
Beer Creek	0	0	0	0	0	1192	937
Provo River	0	13	59	1234	715	1	6
Spring Creek	0	0	0	4	1	18	150

Tributary Habitat Surveys

Adequate spawning habitat was present in reaches sampled in several of the tributaries. Mean spawning substrate for June suckers in the Provo River was significantly different than all the other tributaries (ANOVA: $F = 91.78$; $df = 4, 51$; $P < 0.0001$). The two tributaries that contained adequate spawning substrate were the American Fork and Provo Rivers (Figure 12). Spring Creek did contain some spawning substrate, but only 28% of the total substrate was spawning substrate (Figure 12). Battle Creek's substrate was dominated by clay and filamentous algae; it only contained 1% adequate spawning substrate. Benjamin Slough did not have any adequate spawning substrate in the reach sampled; it consisted of only sand and silt. Mean bank full depth was also significantly different among the tributaries (ANOVA: $F = 9.43$; $df = 4, 51$; $P < 0.0001$). Battle Creek, Benjamin Slough, and Provo River were within the range of what the probability of use curves suggested as being the "ideal" spawning depths (Figure 12). The American Fork River and Spring Creek were significantly lower than the other three tributaries and not within the range of the probability of use curve (Figure 12).

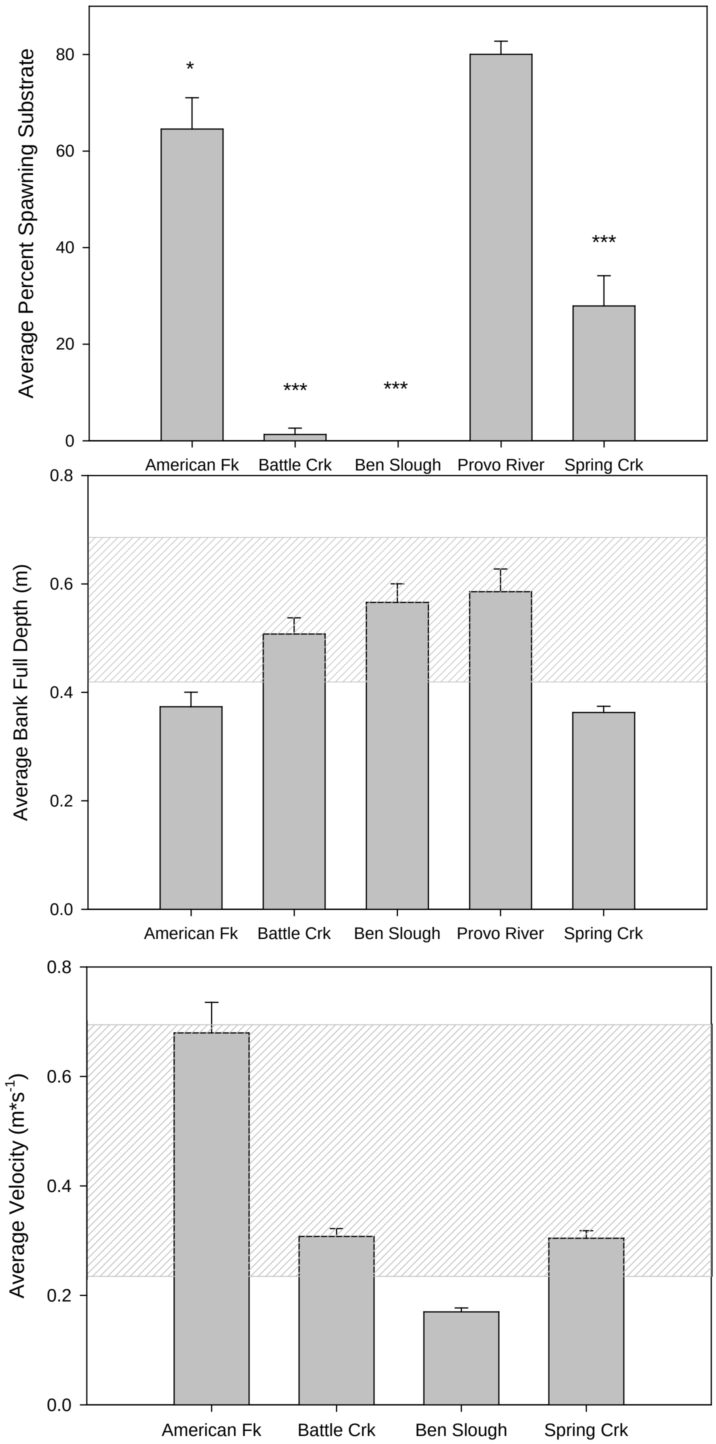

Figure 12. Available spawning habitat for June suckers (+SE) in each tributary. Shaded areas indicate probability of use curves (Radant et al. 1987) for preferred June sucker spawning depths and velocities.

DISCUSSION

By studying population dynamics of imperiled species a better understanding is gained of how well a population is persisting. One key factor in determining if a population is self-sustaining is successful spawning and ultimately recruitment. The results of this study indicate that June sucker can successfully spawn in tributaries other than the Provo River, but spawning success (age-0 production) is dependent upon the presence of quality habitat and good water quality. I found June suckers exhibiting pre-spawning behavior at the mouths of all tributaries sampled except Benjamin Slough. This pre-spawn behavior was inversely related to TDS measured at the tributary mouths. The cue for June suckers to begin their spawning migration was an increase in discharge during the spring, and the act of spawning was likely initiated by a decrease in discharge. The number of fish moving into the tributaries to spawn was inversely related to stream TDS. June suckers were also found to be spawning in tributaries other than Provo River. The evidence of spawning was indicated by the presence of larval June suckers in other tributaries.

Total dissolved solids were the best predictor for the staging behavior model and were the third best at predicting tributary use. The tributary that had the lowest average TDS measurement at the mouth was the Provo River (614 mg L^{-1}); it was also the tributary that had the highest CPUE. The tributary that had the highest average TDS measurement at the mouth was Benjamin Slough (952 mg L^{-1}); it was also the tributary that had the lowest CPUE of June suckers and the only one that did not have suckers demonstrating pre-spawning behavior. Total dissolved solids measured in each tributary was the third best predictor for the number fish moving into each tributary to spawn. An inverse relationship was present for this model as well. The Provo River had the lowest TDS levels (286 mg L^{-1}) and the most fish moving into spawn. Benjamin Slough had the highest TDS levels (984 mg L^{-1}) and no fish moving in to spawn. No studies have investigated the direct relationship between any catostomid species and TDS, but several studies have found negative impacts to different species of fish associated with high TDS levels (Farley 1967; Radtke and Turner 1967; Dickerson and Vinyard 1999). It is understandable that high TDS levels adversely effect fish because the most common ions in TDS measurements are bicarbonate, sulfate, calcium, sodium, and silica (Weber-Sannell and Duffy 2007), most of which negatively impact kidney and gill function (Weber-Sannell and Duffy 2007; Wright 2009). High TDS levels have also proven to negatively impact survival, growth, and spawning of freshwater fishes (Bierhuize and Prepas 1985; Weber-Sannell and Duffy 2007) and hinder fertilization (Stekoll et al. 2001; Brix and Grosell 2005). Although no studies have investigated the negative impacts of high TDS levels on catostomid species, it is not unreasonable to believe that high TDS levels could deter June suckers from spawning based upon the evidence from other species.

Discharge was the best predictor for the tributary use model. The partial dependency plots showed that as discharge increased the number of antenna detections increased as well, but then gradually decreased as discharge continued to decrease. The Provo River was the only tributary that had continuous flow data and a high number of PIT tag antenna detections, so it was the only tributary analyzed graphically, which demonstrated that as discharge increased so did the number of PIT antenna detections. Then as discharge decreased, the number of antenna detections more than double.

Discharge has proven to be a significant cue for many potamodromous fish species (Thurow and King 1994; Schmetterling 2000; Brenkman et al. 2001; Muhlfeld 2002; Holecek and Walters 2007) and many sucker species (Scoppettone et al. 1986; Tyus and Karp 1990; Perkins and Scoppettone 1996; Modde and Irving 1998; Weiss et al. 1998). The timing of the migration relative to the discharge varies, but many studies have found that sucker-spawning migrations are initiated on the ascending limb of the hydrograph and spawning occurs after the peak in discharge (Scoppettone et al. 1986; Tyus and Karp 1990; Perkins and Scoppettone 1996; Modde and Irving 1998; Weiss et al. 1998). Scoppettone et al. (1986) conducted a study to determine life history characteristics of cui-ui. They found that generally cui-ui spawning migration is stimulated by an increase in the flow and spawning occurs after the peak. Physiologically this seems optimal because less energy would be required to spawn after the peak in the hydrograph. Rakowitz et al. (2008) did a synthesis of the available literature on the relationship between water level (discharge) and spawning fish migrations and found that in approximately 70% of the studies, spawning migrations occurred after floods or when water level was dropping. Stamp et al. (2008) did a study that examined the flow regime of the Provo River to determine what flows were necessary for June sucker to successfully spawn. One aspect of the study was to determine what the historical hydrograph of the Provo River resembled. The Provo River drainage typical receives, on average, 12.7 m of snow a year. What generally happens in areas similar to these is the snow in the lower and mid-elevations melt first and create the first peak, then the higher elevations melt with increasing temperatures and create the second peak. Stamp et al. (2008) found that the Provo River historically had a dual peak hydrograph, often having one peak early in the spring (mid-May) then a drop in flow for approximately three weeks, followed by another spike in discharge late in the spring (mid-June). Another study did an analysis of Provo River flows to determine at what discharge, adequate spawning habitat was available for fishes in the Provo River, including June sucker (Olsen et al. 2003). They found at flows between 4.3 and 5.7 m^3s^{-1} the greatest amount of spawning habitat was present in the lower Provo River, for June sucker (Olsen et al. 2003). The average discharge observed during peak spawning in my study was 2.6 m^3s^{-1}, which is lower than the predicted flows Olsen et al. (2003) calculated, but sufficient spawning habitat was present at these lower flows (personal observation). Although the current flow regime in the Provo River reflects significant anthropogenic impacts, the timing of the spawning migration we observed seems to coincide with what historically likely occurred, for June sucker.

Results from this study indicate that the lower abundance of larval June suckers found in tributaries besides the Provo River are likely due to inadequate spawning habitat. Suitable spawning substrate was highly abundant in only two tributaries (American Fork and Provo Rivers). Some gravel and cobble was present in Spring Creek, but most of the substrate was covered with silt. Considering that Spring Creek is spring fed, it will not experience high spring runoff flows. Without the flushing flows, gravels and cobbles will remain covered with silt, making spawning difficult. Sufficient spawning depths were found in three of the five tributaries (Battle Creek, Benjamin Slough, and Provo River). The average bank full depth of the other two tributaries (American Fork River and Spring Creek) was just under what the probability of use curves for June sucker suggests is the ideal depth for spawning (Radant et al. 1987).

Although the American Fork River and Spring Creek were not within the range of depths suggested by the probability of use curve, there were adequate depths and substrates present within both of these tributaries (personal observation). Although spawning did occur and larval June suckers were found in the tributaries other than the Provo River, there were not sufficient enough numbers to maintain a population. If in-stream habitat restoration were to occur it would possibly increase the number of spawning June suckers in the smaller tributaries.

From this study I was able to accurately predict which tributary would have higher larval sucker production based upon water quality measurements, high number of suckers present during staging and spawning periods, and available spawning habitat. The Provo River, which is known to harbor a majority of spawning June suckers, had lower TDS, more suckers staging, more suckers migrating upstream to spawn, and contained more spawning habitat than any other tributary in this study, which subsequently resulted in significantly higher larval production. The tributary that had the highest nutrient loading and no spawning habitat was also the tributary that resulted in no suckers staging, no upstream spawning migration, and no larval production. Thus this study indicates that the factor limiting June sucker spawning in these smaller tributaries is degraded water quality and spawning habitat. The movement behavior of pre-spawning suckers (Appendix 1) in Utah Lake is an indication that the suckers are searching for adequate areas to spawn besides the Provo River. However, because spawning habitat is so limited in these smaller tributaries most suckers typically spawn in the Provo River. Stream restoration projects in the smaller tributaries could provide additional spawning habitat for June suckers. If more spawning habitat is available, the odds of natural recruitment increase. As natural recruitment increases, the June sucker is one step closer to recovery.

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APPENDIX

A1. Movement of suckers between tributaries during spawning period.

PIT Tag Number	Species	First Detection	Date	Time Occupied (d)	Second Detection	Date	Time Occuppied (d)	Time Between(d)
985121008500965	*Chasmistes liorus*	Battle Creek	30-May-08	0.05	Provo River	31-May-08	6	0.02
985121001870904	*Chasmistes liorus*	Battle Creek	30-May-08	0.88	Provo River	12-Jun-08	unknown *	unknown *
985121002039132	*Chasmistes liorus*	Provo River	15-May-08	unknown *	Battle Creek	2-Jun-08	0.01	unknown *
985121002002924	*Catostomus ardens*	Battle Creek	23-May-08	unknown *	Spring Creek	29-May-08	0.007	unknown *