Effects of Flow Fluctuations on the Spawning Habitat of a Riverine Fish

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Abstract - Shallow-water, lithophilic spawning fishes are among the most vulnerable to anthropogenic fluctuations in water levels. We monitored water levels and environmental conditions at the nest sites of *Moxostoma robustum* (Robust Redhorse) on a main-channel gravel bar in the Savannah River, GA–SC. During the course of the 2005 spawning season, over 50% of the observed nest sites were either completely dewatered or left in near zero-flow conditions for several days. This occurred on two separate occasions, once early during the spawning season and then again near its conclusion. We hypothesize the habitat preferences of spawning Robust Redhorse leave them vulnerable to water-level fluctuations, and this phenomenon may be widespread in regulated river systems.

Introduction

Changes in the flow regime of rivers associated with the construction and operation of hydropower facilities affects the availability and quality of fish habitat, ultimately leading to changes in fish assemblage structure (Bunn and Arthington 2002, Freeman et al. 2005, Pringle et al. 2000). Lithophillic spawning fish deposit eggs on or within the substrate in shallow water (Balon 1975). This is a common reproductive strategy utilized by riverine fishes including Cyprinidae (minnows), Catostomidae (suckers), and Salmonidae (salmonids) and, to a lesser extent, by Acipenseridae (sturgeons) and Polyodontidae (paddlefish). These fishes are arguably among the most vulnerable to fluctuations in water levels. For example, the dewatering of salmonid redds in some Pacific northwest drainages due to hydropeaking has been identified as a potentially significant source of mortality in developing eggs (McMichael et al. 2005, Reiser and White 1983, Stober and Tyler 1982). While the phenomenon of nest-site dewatering has not been documented for other taxa, rapid and significant water-level fluctuations occur frequently in regulated rivers throughout the United States (Baxter 1977, Bowen et al. 1998).

Moxostoma robustum Cope (Robust Redhorse) is one example of a species potentially vulnerable to the effects of nest-site dewatering. This

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large riverine catostomid was originally described in 1870 and subsequently "lost" to science for 121 years (Bryant et al. 1996). Native populations are currently known from only three Atlantic Slope drainages (Altamaha, Savannah, and Pee Dee river systems) in North Carolina, South Carolina, and Georgia. It is considered an imperiled species and is the subject of concerted conservation efforts throughout its range. This species spawns in shallow flowing water over gravel substrate in groups of three with a single female flanked by a male on each side, similar to other *Moxostoma* species (Jenkins and Burkhead 1993, Page and Johnston 1990). The triad quivers violently displacing gravel and silt and excavating a shallow depression as gametes are released. Eggs are deposited and develop in the substrate for about five days before hatching (T.B. Grabowski, unpubl. data). Larvae remain in the substrate for an additional 5–10 days before emerging (Weyers et al. 2003) and dispersing downstream.

The Savannah River supports a population of Robust Redhorse restricted to the lower 300-km reach below New Savannah Bluff Lock and Dam (NSBLD), the terminal dam located in Augusta, GA. The Savannah River is among the largest and most regulated of the Atlantic Slope drainages. However due to the eight dams and six reservoirs along the length of the river, Robust Redhorse in the lower Savannah have ready access to a relatively small area of suitable spawning habitat in the form of two mid-channel gravel bars (Grabowski and Isely 2006, 2007). Each gravel bar supports a spawning aggregation of Robust Redhorse in late spring. The smaller and most downstream of these gravel bars appears to consistently attract the largest spawning aggregation (Grabowski and Isely 2007). This gravel bar is located at river kilometer 283, approximately 16 km downstream of NSBLD. The lower gravel bar is approximately 60 m wide and 70 m long. It is a low-relief structure, rising approximately 2 m from the riverbed and is subject to exposure when river discharge falls below approximately 200 $m^3 s^{-1}$. As part of a larger study on the use of gravel bars by the Savannah River catostomid assemblage, we were present to document the effects of water-level fluctuations on the quality and availability of Robust Redhorse spawning habitat.

Methods

We observed the Robust Redhorse spawning aggregation on the lower gravel bar in the Savannah River during 7–18 May 2005. Nest sites were located on six days (8, 9, 10, 11, 12, and 16 May) during this period. We identified nest sites by noting the locations of actively spawning fish and/or visually locating characteristic depressions in the substrate. We then determined their location to within 3 m using a 12-channel hand-held global positioning system receiver (Garmin International, Olathe, KS), and marked each nest site with a surveyor flag. We recorded water depth in the center of the nest site to the nearest 0.01 m using a meter stick. We measured current velocity along the upstream edge of each nest site using a digital stream flow meter (Great Atlantic Flow Meters, Cornwall, UK). Daily and archived river-discharge and gauge-height data were acquired from US Geological Survey Gauging Station 02197000 located at New Savannah Bluff Lock and Dam in Augusta, GA (available online at http://waterdata.usgs.gov/ga/nwis/uv ?2197000).

Results

Changes in discharge and gauge height on the Savannah River appeared to be relatively minor during the period when Robust Redhorse were spawning on the lower gravel bar in 2005 (Fig. 1). River discharge ranged from 130 to 216 $m^3 s^{-1}$, translating to a change of approximately 1.2 m in gauge height. However, mean daily river discharge during 7–17 May 2005 was lower than the mean of mean daily values for the past 98 years of record for that period (t_{14} = -5.82, p < 0.0001). River discharge was below the median discharge for 10 days over this period. River discharge was at or below the 25% quantile over two 2-day periods on 10–11 May and 15–16 May. Of note is the first of these two-day periods, which was preceded by flows exceeding the median on 9 May (Fig. 1).

The Robust Redhorse spawning aggregation initially formed along the west side of the upstream edge of the gravel bar on 8 May 2005 (Fig. 2).

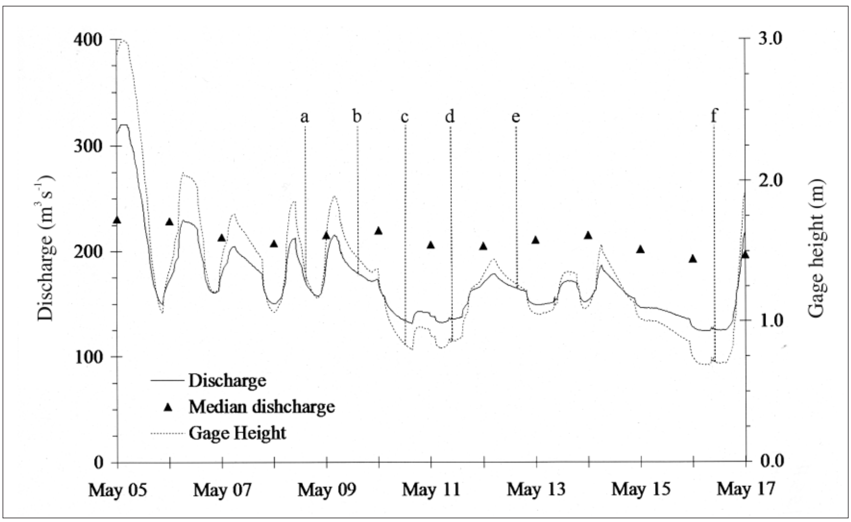

Figure 1. Discharge ($m^3 s^{-1}$) and gage height (m) of the Savannah River during *Moxostoma robustum* (Robust Redhorse) spawning in May, 2005 as measured at New Savannah Bluff Lock and Dam in Augusta, GA. Nest sites were recorded on 08 (a), 09 (b), 10 (c), 11 (d), 12 (e), and 16 (f) May, 2005. Median daily discharge ($m^3 s^{-1}$) based upon data collected 1884–2005.

Over the next two days, active nest sites were spread along both the western upstream edge and the center of the bar. On 10–11 May 2005, river discharge dropped below 142 $m^3 s^{-1}$, leaving approximately 26% of the observed nest sites exposed. An additional 29% of observed nest sites were still underwater in the central portion of the bar (Fig. 2). These nest sites experienced approximately two full days of current velocities at or near

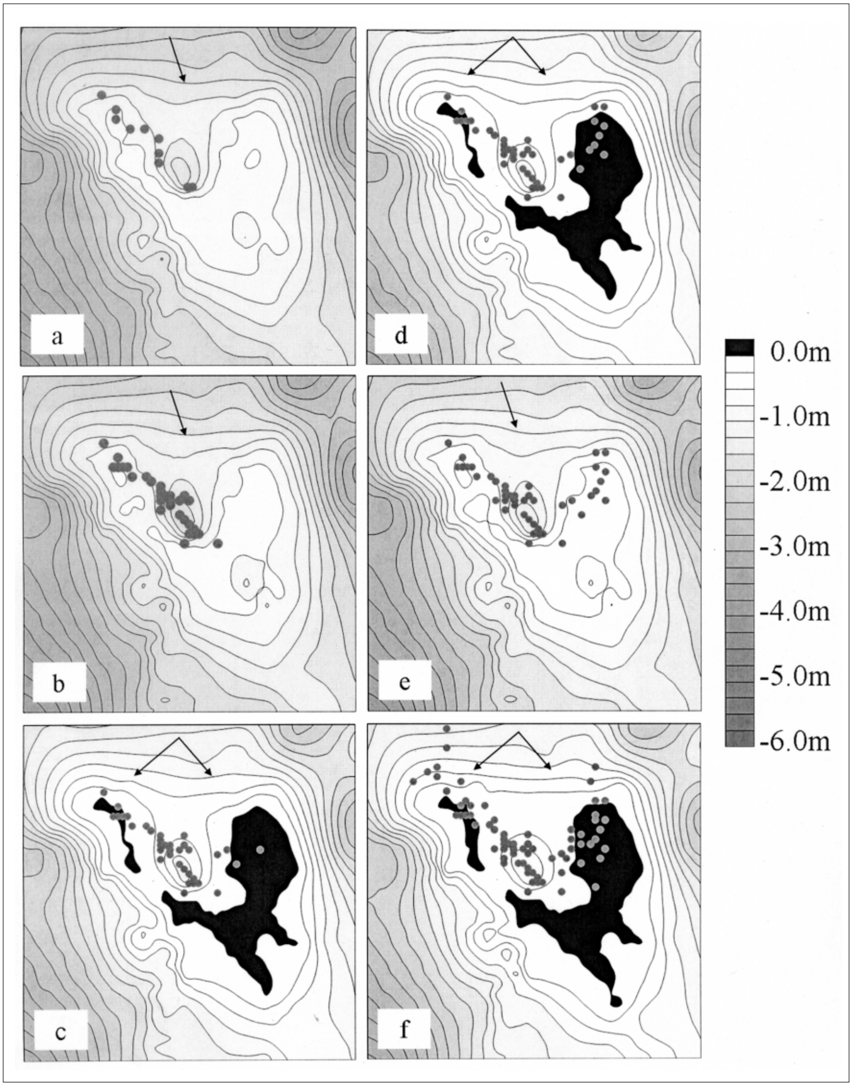

Figure 2. Location of *Moxostoma robustum* (Robust Redhorse) nest sites relative to water levels on the lower gravel bar in the Savannah River during 08 (a), 09 (b), 10 (c), 11 (d), 12 (e), and 16 (f) May, 2005. Black indicates areas that were exposed. Contour lines represent a change in depth of 0.25 m. Arrows indicate the direction of water flow over or around the lower gravel bar.

0.0 m s^{-1} and water depths ≤ 0.25 m. We observed the deposition of silt and other fine sediments over this area. These nest sites were abandoned by spawning adults during this period, but adults returned when water levels increased on 12 May. During the period of 12–16 May, spawning Robust Redhorse spread out along the entire upstream edge of the gravel bar. River discharge dropped again on 16 May and left 27% of nest sites exposed and an additional 33% in near zero-flow conditions.

Discussion

Nest-site dewatering or degradation appears to have two major implications to the Robust Redhorse spawning aggregation on the lower gravel bar in the Savannah River and suggest problems that may arise in other regulated river systems. The first is the potential for increased mortality of embryos and larvae in affected nests. It is unknown to what degree the early life-history stages of Robust Redhorse can tolerate environmental changes such as decreased dissolved oxygen levels or elevated temperatures associated with dewatering. The early life-history stages of some species such as *Oncorhynchus tshawytscha* Walbaum (Chinook Salmon) are surprisingly tolerant (Becker et al. 1983, Neitzel and Becker 1985). For example, developing embryos showed > 90.0% survival rate after being dewatered for 12 days under experimental conditions (Becker et al. 1983). The embryos and larvae in exposed nests could conceivably fare better than those in areas that remain submerged but experience no flow. Numerous studies demonstrate a correlation between increasing sedimentation and decreased survival of developing embryos and larvae incubating in gravel substrates (Chapman 1988, Dilts 1999) or the outright loss from local assemblages of species dependent upon clean gravel substrates for spawning (Sutherland et al. 2002). Depending on the tolerance of the early life-history stages to nest dewatering, mortality may be higher in the nests that remain submerged in zero-flow conditions. Further research is necessary to determine the precise impacts of nest dewatering on survivorship of early life-history stages. The second major implication is the possibility of increased mortality associated with nest superimposition. Falling water levels reduce the amount of suitable spawning habitat available on the lower gravel bar, potentially increasing the risk of disturbance of pre-existing nest sites by spawning adults (Grabowski and Isely 2007, Hayes 1987, McNeil 1964).

Water-level fluctuations on the Savannah River illustrate an example of an ecological trap that likely exists for many species of lithophilic spawning fishes in regulated river systems. An ecological trap is a low-quality habitat that animals use in preference to higher quality, available habitats (Battin 2004, Kokko and Sutherland 2001). Historically in the Savannah River, water-level declines following spring flood pulses would have been more gradual, allowing fish to spawn in very shallow water habitats with enough time for deposited eggs to complete development. Spawning adults may have adapted to assess future habitat suitability based on these historic flow conditions. Cues, such as rising water over shallow or previously exposed gravel substrate, which may have been important indicators of suitable spawning sites during pre-impoundment conditions, are now somewhat maladaptive. Under post-impoundment conditions, the descending portion of the hydrograph is much more abrupt. Individuals responding to these cues explain the formation of new nests on what appears to be dry land in Figure 2 on 11 May. A slight increase in river discharge inundated these areas after nest-site positions had been recorded on 10 May. However, water levels dropped again soon after and remained low when nest positions were recorded on 11 May. Fish spawned in this area instead of attempting to use portions of the gravel bar less susceptible to dewatering or using suitable habitat less susceptible to dewatering on the upstream gravel bar. The impact of nest dewatering on the Savannah River Robust Redhorse population is unknown. We observed a similar pattern of nest dewatering and spawning habitat degradation in 2004, but it is not known how common this phenomenon is on the Savannah River. However, the potential negative impact of repeated spawning seasons with artificially high levels of reproductive failures may have resulted in the currently observed levels of low abundance. Habitats similar to the gravel bar described in this paper are used by other catostomids (Grabowski and Isely 2007) and numerous other species. The effects of water-level fluctuations in regulated rivers on lithophilic spawning riverine species warrants further study.

Acknowledgments

We thank K. Meehan, M. Noad, and N. Ratterman for their assistance in the field. E. Eidson and the Phinizy Swamp Nature Park provided logistical assistance for this study. Cooperating agencies for the South Carolina Cooperative Fish and Wildlife Research Unit are the US Geological Survey, the US Fish and Wildlife Service, Clemson University, the Wildlife Management Institute, and the South Carolina Department of Natural Resources.

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