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Effects of Experimental High Flow Releases and Increased Fluctuations in Flow from Glen Canyon Dam on Abundance, Growth, and Survival Rates of Early Life Stages of Rainbow Trout in the Lee's Ferry Reach of the Colorado River

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The abundance of adult fish populations is controlled by the growth and survival rates of early life stages. Evaluating the effects of flow regimes on early life stages is therefore critical to determine how these regimes affect the abundance of adult populations. Experimental high flow releases from Glen Canyon Dam, primarily intended to conserve fine sediment and improve habitat conditions for native fish in the Colorado River in Grand Canyon, AZ, have been conducted in 1996, 2004, and 2008. These flows potentially affect the Lee's Ferry reach rainbow trout population, located immediately downstream of the dam, which supports a highly valued fishery and likely influences the abundance of rainbow trout in Grand Canyon. Due to concerns about negative effects of high trout abundance on endangered native fish, hourly variation in flow from Glen Canyon Dam was experimentally increased between 2003 and 2005 to reduce trout abundance. This study reports on the effects of experimental high flow releases and fluctuating flows on early life stages of rainbow trout in the Lee's Ferry reach based on monthly sampling of redds (egg nests) and the abundance and growth of age-0 trout between 2003 and 2009.

Data on spawn timing, spawning elevations, and intergravel temperatures were integrated in a model to estimate the magnitude and seasonal trend in incubation mortality resulting from redd dewatering due to fluctuations in flow. Experimental fluctuations from January through March promoted spawning at higher elevations where the duration of dewatering was longer and intergravel temperatures exceeded lethal thresholds. Flow-dependent incubation mortality rates were 24% (2003) and 50% (2004) in years with higher flow fluctuations, compared to 5-11% under normal operations (2006-2009). Spatial and temporal predictions of mortality were consistent with direct observations of egg mortality determined from the excavation of 125 redds. The amount of variation in backcalculated hatch date distributions predicted by flow-independent (84-93%) and flow–dependent (82-91%) incubation loss models were similar. Age-0 abundance was generally independent of viable egg deposition, except in one year when egg deposition was 10-fold lower due to reduced spawning activity. There was no evidence from the hatch date or stock-recruitment analysis that flow-dependent incubation losses, although large in experimental years, affected the abundance of the age-0 population. The data indicate that strong compensation in survival rates shortly after emergence mitigated the impact of flow-dependent losses.

Multiple lines of evidence demonstrated that the March 2008 high flow experiment (HFE) resulted in a large increase in early survival rates (fertilization to $\sim$1-2 months from emergence) of age-0 trout due an improvement in habitat conditions. A stock-recruitment analysis indicated that age-0 abundance in July 2008 was over four-fold higher than expected given the number of viable redds that produced these fish. A hatch date analysis indicated that early survival rates were much higher for cohorts that emerged about two months after the HFE. These cohorts, which were fertilized after the HFE, were not exposed to high flows and emerged into better quality habitat. Inter annual differences in growth of age-0 trout based on otolith microstructure support this hypothesis. Growth rates in the summer and fall of 2008 (0.44 mm·day-1) were virtually the same as in 2006 (0.46 mm·day-1), the highest recorded over six years, even though abundance was eight-fold greater in 2008. I speculate that high flows in 2008 increased interstitial spaces in the substrate and food availability or quality, leading to higher early survival of recently emerged trout and better growth during summer and fall. Abundance

in 2009 was over two-fold higher than expected, possibly indicating that the effect of the HFE on early life stages was somewhat persistent.