Effects of Water-level Reductions on Littoral Habitat and Recreational Access in Brazos River Reservoirs, Texas

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Abstract: Reservoirs provide recreational opportunities along with water supplies, flood control, and hydroelectricity. Although recreational values are often considered in water management plans, reservoir regulators often lack data to evaluate the impacts of operations on fish habitat and recreational access. We partnered with the Brazos River Authority (BRA) and used reservoir bathymetry and side-imaging sonar data to investigate the effects of reservoir water-level changes on littoral habitat characteristics and boat access in 11 BRA reservoirs. Littoral area, coarse substrate, and submerged aquatic vegetation generally declined with decreasing water level. Availability of large woody debris in the littoral zone was stable as water levels declined. The magnitude of these responses varied among reservoirs, likely due to differences in reservoir morphology. Effects of water-level reductions on boat access were also reservoir specific: complete loss of access occurred with 2 m of water loss in some reservoirs while in others all access remained useable even if water levels declined up to 5 m. Categorizing the magnitude of these responses aided in identifying reservoirs most sensitive to water-level change. These data facilitated our ability to work proactively with the BRA to incorporate fishery considerations into water management planning and prioritize future habitat and access enhancement efforts.

Key words: boat access, large woody debris, submerged aquatic vegetation, reservoir water level

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Reservoirs provide many important services, including municipal water supplies, flood control, and hydroelectricity (Allen et al. 2008). Secondary benefits of many reservoirs are the opportunities created for aquatic recreation, including fishing and boating. Reservoir fisheries alone are responsible for billions of dollars in total economic impact (Miranda et al. 2010, U.S. Fish and Wildlife Service and U.S. Census Bureau 2011). These systems are particularly important in the southern United States, where they constitute the majority of lentic waters (Jenkins 1967, Fisher et al. 1986). Therefore, reservoir fisheries are of critical importance to many fisheries managers.

Managing reservoir fisheries can be challenging due to the dynamic nature of the reservoir environment (Allen et al. 2008). For example, reservoirs created to meet water supply or electricity needs can experience abrupt changes in water level in response to human demands. Reservoir water levels can also be affected by downstream minimum flow requirements and regional climate trends, such as drought. These fluctuations, whether natural or anthropogenic, can significantly affect the quality and quantity of littoral fish habitat and recreational access (Gasith and Gafny 1990, Fischer and Öhl 2005, Daugherty et al. 2011). Many studies have reported relationships among reservoir water levels, fish population dynamics, and recreational use (e.g., Miranda et al. 1984, Jakus et al. 2000, Hanson et al. 2002, Sammons et al. 2002, Fischer and Öhl 2005, Daugherty et al. 2011). Therefore, understanding the effects of water levels on littoral habitat characteristics and recreational access are essential components of reservoir fisheries management.

Increased appreciation of the societal and economic values of reservoir fisheries has elevated their consideration in water resource planning. However, water regulators often lack the expertise needed to quantify the effects of various operating strategies on fisheries. State fish and game agencies are usually tasked with managing reservoir fisheries, and can provide comprehensive understanding of the effects of water levels on fish habitat and access. Therefore, collaborations between reservoir regulators and state fish and game agencies provide an opportunity to consider fisheries in the water management planning process.

The Brazos River Basin, located in central Texas, includes 19 major reservoirs. Water rights in a majority of these lakes are managed by the Brazos River Authority (BRA). In 2004, the BRA submitted a water right permit application to address current and future water needs throughout the Brazos River Basin. As part of the process, the BRA was required to submit a comprehensive water management plan (WMP) for approval by the Texas Commission on Environmental Quality. Within the WMP, the BRA sought to develop reservoir operational guidelines that considered the impacts of water-level management on reservoir fisheries. To do so, the BRA partnered with the Inland Fisheries Division of the Texas Parks and Wildlife Department (TPWD) to assess the effects of water-level fluctuations on fish habitat and recreational access of the reservoirs included in the WMP. Therefore, our primary objectives were to (1) develop an efficient assessment technique to quantitatively characterize the quantity and quality of both littoral habitat and recreational access, and (2) develop spatially-explicit simulation models to assess the impacts of changing water levels on these factors in BRA reservoirs. Our methodology can be used to minimize the negative effects of current and future water management practices on reservoir fisheries and aid in prioritizing fishery enhancement projects.

Methods

Study Sites

The Brazos River begins in New Mexico and meanders southeasterly approximately 2060 km to its confluence with the Gulf of Mexico near Freeport, Texas. The watershed comprises 115,565 km^2, 94% of which is in Texas. The BRA maintains water diversion rights in 11 reservoirs in the basin (Table 1). These reservoirs provide a multitude of services, and popular fisheries for catfishes (*Ictalurus* spp.), black basses (*Micropterus* spp.), temperate basses (*Morone* spp.), and crappies (*Pomoxis* spp).

Table 1. Summary statistics for Brazos River study reservoirs, sampled during June and July 2012. "D_L" refers to the shoreline development index as defined by Hutchinson (1957).

Reservoir	Surface area (ha)	D_L	Boat access sites	Secchi depth (m)	Annual water-level variation (m)
Georgetown	566	4.9	3	1.8	5.3
Aquilla	1258	5	3	1.2	1.1
Granger	1735	4.3	5	0.6	1.2
Proctor	1860	3.8	4	1.8	3
Stillhouse Hollow	2570	5.2	4	3.7	1.1
Granbury	3058	8.4	5	1.8	< 0.5
Somerville	4650	5.7	11	4.3	1
Limestone	4934	7.9	4	1.2	0.5
Belton	4939	8.8	17	2.4	1.2
Possum Kingdom	6670	14.8	9	3	< 0.5
Whitney	13,030	10.5	14	2.4	1.8

Side-scan Sonar Data Acquisition

In June and July 2012, littoral habitat was characterized at 75 sites within each of the 11 BRA reservoirs using georeferenced, side-scan sonar imagery (Kaeser and Litts 2008, Kaeser and Litts 2010). Sampling sites were selected following a stratified, random sampling design. Each reservoir was divided into three reaches (i.e., upper, middle, and lower reaches) along the longitudinal axis using a geographic information system (GIS; ArcGIS 9.3, Environmental Systems Research Institute [ESRI]; Redlands, California). Within each reach, 25 sites along the reservoir shoreline were selected using random selection routines in the GIS environment (Daugherty et al. 2011). We assumed that our stratified, random sampling design resulted in an unbiased estimation of littoral habitat change in response to water-level change at the reservoir scale.

At each sampling location, a Humminbird side-imaging system (model 1198c; Johnson Outdoors Marine Electronics, Inc., Eufaula, Alabama) was used to capture sonar recordings of submerged habitat at each sampling location. The system used a bow-mounted transducer and GPS receiver (horizontal accuracy ± 2.5 m) to produce high-resolution (< 10 cm) imagery used to characterize physical habitat (Kaeser and Litts 2008, Kaeser and Litts 2010). Sonar recordings of shoreline habitat were collected by navigating a transect parallel to the reservoir shoreline for a minimum of 50 m at each sampling site; recordings were also collected along transects perpendicular to the shoreline for a minimum distance of 200 m, or to the water depth that corresponded to 30% of reservoir storage capacity, which served as the minimum reservoir water level as defined in the WMP. Boat speed during sonar surveys ranged from 6 to 8 km h^{-1}, and sonar range was set at 23 m per side. Sonar recordings were also collected at all boat access sites following the same protocol.

GIS Analyses

Side-scan Sonar Data Processing. ArcGIS 9.3, coupled with DrDepth Sea Bottom Mapping Software (v. 5.0.1; Per Pelin, Göteborg, Sweden), were used to transform sonar recording files into spatially explicit sonar mosaics. DrDepth was used to perform slant range correction and remove distortion near image centers (Fish and Carr 1990, Kaeser and Litts 2010); corrected imagery for each sampling site were then exported as ESRI grid files. ArcCatalog was then used to create a mosaic of image transects for each reservoir. Habitat features, including substrate, large woody debris (LWD), and submerged aquatic vegetation (SAV) at each sampling site were then manually delineated as independent polygon shapefiles within the GIS environment as described by Kaeser and Litts (2008, 2010). We delineated substrates as either fine (e.g., sands, silts, clays or organic detritus particles less than 2 mm in diameter) or coarse (e.g., gravels, cobbles, and bedrock greater than 2 mm in diameter) (Kaeser and Litts 2010). For sonar recordings of boat access sites, the end of each public boat access ramp was identified from sonar mosaics and plotted as a point shapefile in the GIS environment.

Reservoir Bathymetry Data Processing. The BRA provided polyline shapefiles of reservoir bathymetry for each reservoir (vertical resolution = 0.6 to 1.2 m). These data were used to characterize littoral area and habitat characteristics at a given reservoir water level. Beginning at conservation pool height, defined as the elevation at which the reservoir reaches full storage capacity (BRA; http://waterschool.brazos.org/post/conservation-pool.aspx), successively lower contours were extracted using select-by-attribute routines and processed into independent polygon layers depicting the reservoir surface at each water level.

Littoral area (i.e., quantity) and spatial extent were then determined at each water level by extracting the difference in surface area between water-level specific polygons using the erase features tool in XTools Pro (version 3.2.0; Data East, Novosibirsk, Russia) and processing the result into a new polygon shapefile. The depth of the littoral zone was based on the depth of the photic zone in each reservoir, as measured by long-term average Secchi depth recordings (TPWD, unpublished data, Table 1). This measure was then used to select the appropriate water-level specific polygons for analysis. For example, if reservoir Secchi depth was 3 m, the process of determining littoral habitat area and spatial extent would begin by extracting the difference between the reservoir polygon at conservation pool and that 3 m below conservation pool. This process was then repeated at 1-m increments through 5 m of water loss in each reservoir.

Polygon shapefiles depicting the spatial extent of the littoral zone at each water level were plotted over delineated littoral habitat data in the GIS environment to assess littoral habitat quality. Select-by-location routines were then used to characterize littoral substrate composition and the availability of LWD (i.e., downed and standing timber) and SAV at each water level in each reservoir. We defined littoral habitat quality using these metrics because they have been found to influence the reproductive success, growth, and recruitment of many reservoir fishes (e.g., Savino and Stein 1982, Beam 1983, Dibble 1993, Irwin 1994, Annett et al. 1996). For recreational access, we plotted the point shapefile depicting the ends of boat ramps in each reservoir along with the water-level specific reservoir polygons and used select-by-location routines in GIS to identify boat ramps that remained inundated at each water level.

Data Analyses

Results of the GIS analyses were used to calculate the change in each metric, expressed as the percentage of availability at conservation pool, at each water level and reservoir. We plotted the distribution of responses using box-and-whisker plots, and used quantile regression of the median to describe the direction and rate of change for each metric examined. Preliminary diagnostics indicated the response of SAV was nonlinear; therefore, the data were square root transformed prior to regression analyses. In addition, we classified the sensitivity of each study reservoir to water-level changes for each metric using the percentiles derived from the box-and whisker plots. Reservoirs in the lower quartile were classified as exhibiting high sensitivity to water-level change, whereas reservoirs that fell in the upper quartile were classified as exhibiting low sensitivity. Reservoirs in the interquartile range were classified as moderately sensitive. Statistical analyses were conducted using SAS Enterprise Guide 4.3 (SAS Institute, Inc.; Cary, North Carolina) and were considered significant at an $\alpha = 0.05$ level of confidence.

Results

Habitat and access data were collected at 904 sites in the 11 study reservoirs. Littoral area generally declined with reductions in water level; regression of the median responses indicated about 8% of the littoral area available at conservation pool was lost for each 1-m reduction in pool height (Figure 1). However, responses varied among the study reservoirs. Littoral area in Stillhouse Hollow and Granbury reservoirs was classified as highly sensitive water-level change, with reductions in littoral area of up to 90%. In contrast, littoral area in Limestone, Belton, and Possum Kingdom reservoirs was not sensitive to water-level change, with increases in littoral area observed in two of these reservoirs. Littoral area was moderately sensitive to water-level change in the remaining six reservoirs examined (Table 2).

Similar to littoral area, coarse substrate availability declined as water levels were reduced, at a rate of about 16% per m of water loss (Figure 1). Georgetown and Aquilla reservoirs were classified as highly sensitive, with up to a 95% reduction in coarse substrate availability. Reduction in coarse substrate availability in Whitney Reservoir was less than 15%, and a 25% increase was observed in Possum Kingdom Reservoir.

Large woody debris availability was generally resilient to reductions in water level, exemplified by a 7% increase in availability for each m of water loss (Figure 1). However, LWD availability in

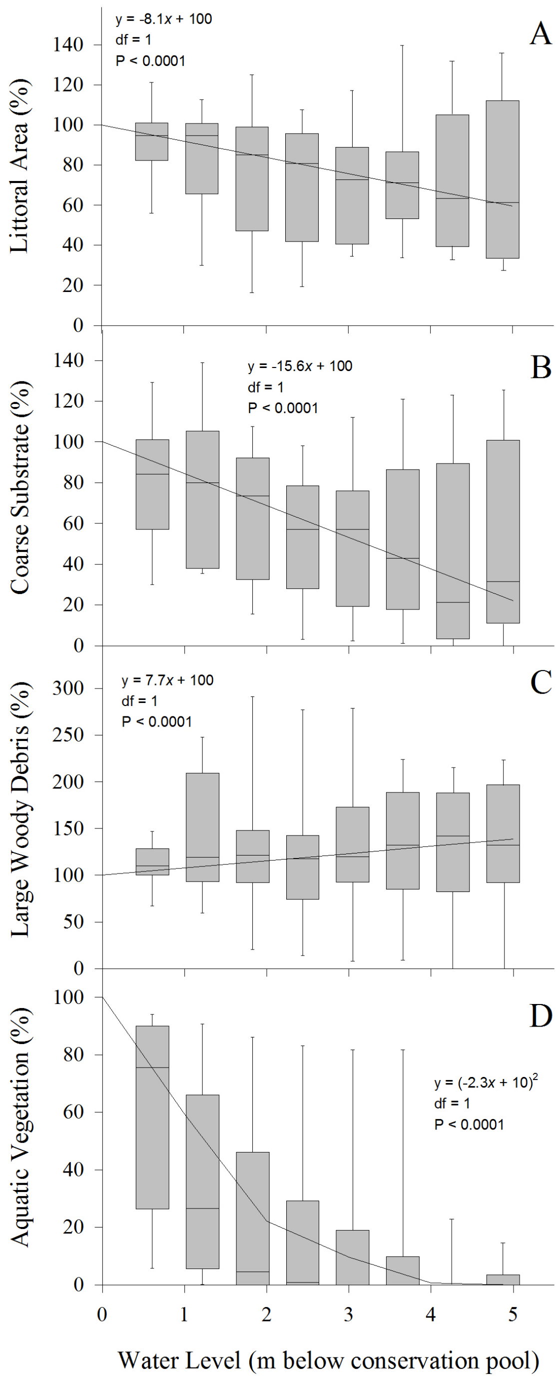

Figure 1. Box-and-whisker plots of change (%, relative to availability at conservation pool) in littoral area (panel A), coarse substrate (panel B), large woody debris (panel C), and submerged aquatic vegetation (panel D) through 5 m of water loss in 11 Brazos River basin reservoirs, Texas. Box represents the median and 25th and 75th percentiles, whiskers represent the 5th and 95th percentiles. The solid line represents the quantile regression of the median response. Regression line for submerged aquatic vegetation was plotted using back-transformed data.

Table 2. Sensitivity classifications of study reservoirs based on GIS-modeled responses to water-level reduction through 5 m from conservation pool. "High" indicates sensitivity to water-level change for a given metric (i.e., <25th percentile of the response distribution), whereas "Low" indicates insensitivity (i.e., >75th percentile). Reservoirs classified as "Moderate" exhibited responses in the interquartile range.

Reservoir	Littoral area	Coarse substrate	LWD	SAV	Boat access
Georgetown	Moderate	High	Moderate		Low
Aquilla	Moderate	High	Low	High	Moderate
Granger	Moderate	Moderate	Low	High	Moderate
Proctor	Moderate	Low	High	Moderate	Moderate
Stillhouse Hollow	High	Moderate	Moderate	Low	Low
Granbury	High	Moderate	Moderate	High	High
Somerville	Moderate	Moderate	High	Moderate	Moderate
Limestone	Low	Moderate	Moderate	Moderate	High
Belton	Low	Moderate	Moderate	Moderate	Moderate
Possum Kingdom	Low	Low	Low	Moderate	Low
Whitney	Moderate	Low	Moderate	Low	Moderate

Proctor and Somerville reservoirs was classified as highly sensitive to water-level reduction (Table 2). In Proctor reservoir, LWD became unavailable with 3 m of water loss from the system; and Somerville reservoir was reduced by over 60% (Figure 1, Table 2). In contrast, LWD availability effectively doubled in Aquilla and Possum Kingdom reservoirs with 5-m reduction in water level.

The availability of SAV was highly sensitive to water-level change, characterized by an exponential decline in availability in most of the reservoirs examined (Figure 1, Table 2). With the exception of Stillhouse Hollow and Whitney reservoirs, SAV became unavailable within 4-m of water loss (Figure 1). Submerged aquatic vegetation in Aquilla, Granger, and Granbury reservoirs exhibited the greatest sensitivity to water levels, with complete loss within one to two m of conservation pool.

Similar to the littoral habitat metrics we examined, recreational access generally declined at lower reservoir water levels (at a rate of about 13% per m of water loss), and relationships differed among reservoirs (Figure 2; Table 2). Boat access at Georgetown, Stillhouse Hollow, and Possum Kingdom reservoirs was not sensitive to water-level reductions, with 75% to 100% of sites remaining usable through 5 m of water loss. In contrast, all boat access sites became unusable in Limestone and Granbury reservoirs with 2 m of water loss in these systems.

Discussion

Our study results generally identified negative effects of reservoir water-level reductions on fish habitat; however, results varied greatly among the reservoirs examined. Irwin and Noble (1996) reported decreases in reservoir water levels of less than 2 m significantly reduced littoral cover and coarse substrate availability in

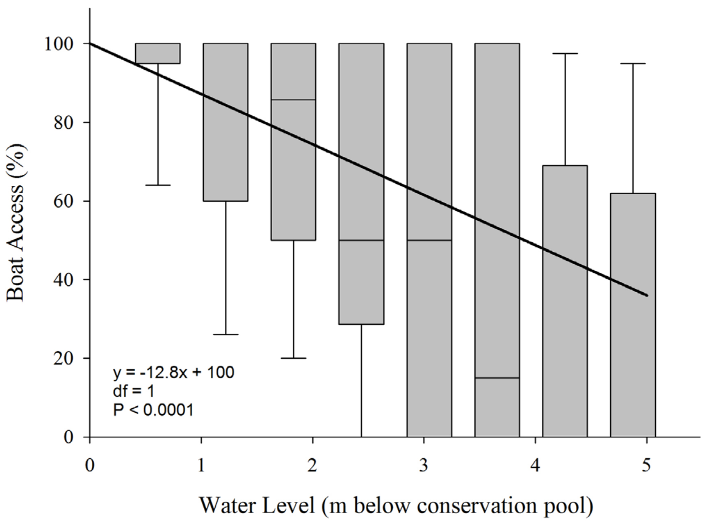

Figure 2. Box-and-whisker plots of change (%, relative to availability at conservation pool) in boat access through 5 m of water loss in 11 Brazos River basin reservoirs, Texas. Box represents the median and 25th and 75th percentiles, whiskers represent the 5th and 95th percentiles. The solid line represents the quantile regression of the median response.

B. E. Jordan Reservoir, North Carolina. Gasith and Gafny (1990) reported a transition from coarse to fine substrates with a 4 m decrease in water level in Lake Kinneret, Israel, and Beauchamp et al. (1994) estimated a 20% loss in coarse substrates following a 2 m reduction in Lake Tahoe, California-Nevada. Changes in substrate and structural habitat characteristics, such as SAV, are known to impact fish populations, as the availability of these habitat types regulates reproductive success and recruitment to the fishery (Dibble 1993, Walters and Juanes 1993, Irwin 1994, Annett et al. 1996, Irwin et al. 1997). Our results, coupled with those of previous studies, illustrate the importance of understanding the responses of fish habitat to water-level change both within and among reservoirs.

Modeling the effects of water-level change provided a science-based approach for evaluating the effects of reservoir operating strategies on fish habitat and recreational access. The metrics we examined were highly sensitive to reductions in water level in some reservoirs, but less affected in others. Although we did not investigate the causal mechanisms underlying these differences, the variable responses we observed were likely the result of differences in basin morphology. The extent of littoral habitat in reservoirs varies, based in part by the characteristics of the inundated stream and river valleys from which they are formed (Irwin and Noble 1996, Dagel and Miranda 2012). Dendritic, shallow-sloped basins are more likely to remain connected to the original river floodplain as water levels change than reservoirs created in entrenched reaches where the floodplain was constricted (Dagel and Miranda 2012). The shoreline development index (SDI), which describes shoreline irregularity and littoral-zone potential (greater values indicate greater irregularity; Hutchinson 1957, Miranda et al. 2008) provides on objective metric for evaluating relationships between reservoir morphology and habitat. Mean SDI was greater among reservoirs in which littoral area was impacted least by water-level change (10.5), when compared to reservoirs exhibiting high sensitivity (6.8). Similarly, mean SDI in reservoirs where coarse substrates were insensitive to water-level change was 9.7, whereas mean SDI was 5.0 in reservoirs with highly sensitive coarse substrate availability. These relationships support the hypothesis that basin morphology plays an important role in the response of reservoir habitat to water-level change.

Many reservoir fish populations are closely linked to littoral habitat. For example, the availability of coarse substrates, LWD, and SAV are positively related to production for many centrarchids (e.g., Meals and Miranda 1991, Irwin et al. 1997, Dagel and Miranda 2012). Therefore, fishery dynamics within these reservoirs should reflect similar relationships to those among water levels and littoral habitat characteristics we observed in our study. The differing responses we observed among reservoirs suggests that reservoir regulators and fishery managers responsible for multiple reservoirs within a basin should consider opportunities to manage at a basin scale, rather than making decisions at the reservoir-specific level. Maintaining higher water levels during critical periods in reservoirs highly sensitive to water-level reductions, at the expense of those less affected by water-level change, would optimize fishery quality among reservoirs. Reservoir-specific data also provided a means to determine minimum water levels that support abundant, high-quality fish habitat in each reservoir. In the event that these water levels cannot be maintained, our results are useful for identifying and prioritizing fishery management activities, such as habitat enhancement or fish stocking, to mitigate negative effects.

In 2012, about 81% of freshwater anglers in Texas fished one or more days in reservoirs from a boat, and 28% were unwilling to substitute another water body for their preferred fishing location (Landon et al. 2012). Similar trends are known to exist on a national scale (USFWS and U.S. Census Bureau 2011). These data suggest loss of boat access is likely to negatively impact fishing participation, and illustrate the importance of providing recreational access to reservoirs throughout the state. Maintaining adequate access involves a different set of challenges and opportunities than managing reservoir water levels for fish production. Due to the variable nature of multi-use reservoirs, maintaining reservoir water levels to ensure accessibility is unlikely; more practical approaches include the alteration of existing access locations to remain useable over a greater range of water levels (i.e., launch extension) and the procurement of additional access sites (Daugherty et al. 2011). The resilience of boat access we observed in Georgetown, Stillhouse Hollow, and Possum Kingdom reservoirs was the result of boat ramps being constructed on high gradient (i.e., ≥10% slope) shorelines and relatively long ramps compared to other study reservoirs. The BRA used the results of our study to prioritize and implement recreational access improvement projects. In 2013, the BRA modified access sites at Lake Granbury and Lake Limestone reservoirs, including lengthening and widening boat ramps, dredging, and providing temporary extensions during low-water conditions.

Understanding the effects of water-level change on littoral habitat and recreational access is an important first step toward ensuring that fishery needs are considered in decisions regarding reservoir water management. The use of the side-scan sonar and GIS data provided an efficient means to collect and predict the effects of reservoir water-level change on the metrics we examined. These data were used within the BRA WMP to identify reservoir-specific, minimum water levels that maintain availability of quality littoral fish habitat, and were incorporated into reservoir operating guidelines at the basin scale. Our results were essential to improving our ability to work proactively with the BRA to incorporate fishery considerations into reservoir water management planning.

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