Establishing Ground Cover in Reservoir Mudflats to Foster Fish Assemblages

Progress Report

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Executive Summary

With a median age of nearly 70 years, reservoirs in the USA are showing compelling signs of fish habitat degradation, particularly in littoral areas. To rejuvenate these fish habitats we are researching the establishment of agricultural plantings on reservoir mudflats. Several agricultural plant species commonly used for wildlife food plots were selected for planting based on their ability to grow during winter and under diverse soil quality conditions. Over the course of two weeks in October, 2016 and 2017, we established 30-40 experimental plots each year by disking and seeding approximately 50 acres of exposed shorelines using ATV-towed seeding implements. Success of establishment was evaluated with surveys conducted monthly throughout the following winter and into spring.

In the 2016-2017 growing season, two grass species, ryegrass and triticale, performed well in mudflats despite poor soils with acidic pH. Ryegrass excelled in ground cover and biomass, and triticale in maximum height. These complementing features contribute to diversity of fish habitat structure. In general, forbs (grasses) performed better on mudflats than legumes (clovers), or than legume-forb mixed plantings. However, the 2016-2017 fall-winter period was unusually dry potentially hampering plant growth, so further evaluation is needed.

In the 2017-2018 growing season, repeat species from the previous season as well as new test species had become established by January 2018. However, excessive rainfall in February 2018 prompted the USACE to raise water level ahead of schedule. Consequently, our crops were submerged before they could attain full size and we were unable to evaluate growth or benefits to fish.

During our study, evaluation of ground cover in mudflats has been hampered by unpredictable water levels. In Spring 2017, because of below average rainfall, reservoir water level did not reach normal pool, which allowed plant growth but precluded evaluation of plant benefits to fish. Conversely, in Spring 2018, excessive rainfall flooded crops before they could attain full growth and several weeks before the spawning season. Therefore, in our second season we were able to evaluate neither plant growth nor benefits to fish. Consequently, we have extended this evaluation into a third year. In October 2018 we will re-plant the study area and repeat the evaluation under the expectation of a normal water level year. Our results so far suggest that selected plant species grow well in mudflats, but growing crops in reservoirs with highly unpredictable water levels has risks that in many cases may not be permissible.

After flooding terrestrial plants start to degrade, their persistence under water can determine value as fish habitat. Persistence of terrestrial plants after inundation was evaluated in experimental tanks. We submerged various plant species for over 3-month to simulate the length of time mudflats are flooded in Enid Reservoir. Legumes showed major degradation in the first few weeks, whereas forbs retained adequate structure over several months. Mature ryegrass and triticale may provide adequate structure for fish for the entire flooding season. Ryegrass lost stems and produced large gaps among vegetation and thus may produce suitable adult fish habitat. Triticale remained dense and complex and thus may support suitable juvenile fish habitat.

Fish attractors such as brush piles have often been placed in reservoir mudflats to provide habitat diversity and cover for fish. However, their performance has remained mostly unevaluated. An evaluation would benefit existing fish attractor programs supported by our cooperators (i.e., MDWFP, USACE, RFHP, and USFWS). Thus, to fully use available resources committed to this research we switched our scheduled evaluation of fish in planted plots to an evaluation of installed fish attractors. In early 2017 the USACE in cooperation with local fishing clubs established nearly 200 fish attractors (brush piles) in our study site. We used rotenone to sample 120 sites with and without (control) brush piles, in May-September, 2017. Abundances of juvenile fish and their average size differed. Three species, bluegill, largemouth bass, and black crappie showed higher abundance in brush piles as compared to control sites. Juvenile fish in brush piles were larger than those in control sites during a majority of the sampling season. We also detected differences in fish association with brush piles in relation to pile size and depth location. Increasing the percentage of brush within a reservoir increases the density of juveniles of selected species and bring densities closer to levels seen in naturally-vegetated lakes, or in flooded wooded areas of the riparian zone.

In the upcoming year we plan to replant the mudflats in October, monitor plant growth through fall, winter, and early spring, and estimate fish and invertebrate benefits in late spring and early summer. We will also be completing a tank study designed to assess use of ryegrass and triticale by species commonly found in the mudflats of Enid Lake.

Introduction

Aging reservoirs throughout the country pose a major obstacle for resource managers in maintaining desirable recreational fisheries. Degradation of shorelines and nearshore areas through erosion, sedimentation, loss of submerged structure, and widespread substrate homogenization all have become a common concern for reservoir managers because they may decrease habitat complexity (Allen and Aggus 1983; Miranda and Krogman 2015; Pegg et al. 2015). Decreasing habitat complexity can negatively impact fish diversity, simplify fish communities, alter species composition, and reduce recruitment of fish species that support key recreational fisheries (Valley et al. 2004; Smokorowski and Pratt 2007).

Reservoirs can experience dramatically different hydrologic conditions from those that existed in the river prior to impoundment. During flood events rivers escape their banks inundating the surrounding floodplains generally during the late winter through spring. Inundation allows fish access to terrestrial vegetation that provides novel habitat and a boost in productivity (Petry et al. 2003). While impounded systems provide permanent exposure to floodplain habitats, the unnatural water cycle allowing flooding to persist during the growing season limits the growth of terrestrial vegetation and slowly degrades the productive capacity of floodplains (Agostinho et al. 1999; Miranda 2008).

Habitat manipulation and enhancement is a potential solution to mitigate the impacts of reduced habitat complexity. Methods for slowing the rate or reversing reservoir senescence exist and could help restore and preserve habitat (Allen and Aggus 1983; Miranda and Krogman 2015; Pegg et al. 2015). These methods include the creation of habitat components using both artificial structures and naturally occurring materials as well as through the use of both terrestrial and aquatic vegetation. Restoration of degraded ecosystem goods and services, and providing opportunities for resource users, are primary goals of habitat management (Pegg and Chick 2010).

Submersed terrestrial vegetation in the floodplain of a river serves as an important structure for many fish species adapted to exploit seasonally-inundated floodplains. These include various species that provide socially and economically important recreational fisheries (USFWS 2011; Hutt et al. 2013). Studies consistently report that fishes exhibit greater species diversity in vegetated than in non-vegetated areas (Dibble et al. 1996; Cross and McInerny 2001; Pratt and Smokorowski 2003). Vegetation can benefit fish through various mechanisms, often varying across and within a species at different stages of development. For example, forage species use vegetation as protection from predators and predatory fish have reduced foraging success in heavy cover (Savino and Stein 1988, 1989). Vegetation also provides a substrate for growth of epiphytic plants and invertebrates (Keast 1984; Rooke 1986; Chilton 1990; Humphries 1996), which provide forage for juveniles and adult fish (Moxley and

Langford 1982). Many fishes depend on vegetation for nest building and spawning as well as structure for young of year (Poe et al. 1986; Bryan and Scarnecchia 1992).

Many reservoirs are characterized by large seasonal or long-term water level fluctuations. These fluctuations generally occur over elevation contours that were once uplands and are now artificially submerged. These uplands have soils, slopes, and seed banks that are different from natural floodplains, and therefore are unable to support the vegetation assemblages that commonly develop in natural floodplains. As a result, the regulated zone of a reservoir (i.e., the contour elevations between conservation and normal pool) are often barren mudflats (Figure 1). Excessive mudflats are a problem in reservoirs nationwide, and has been identified by MDWFP as a major issue limiting fish production in flood control reservoirs in north Mississippi.

Figure 1. Long Branch creek on Enid Lake on 28 November 2013 at 71.35 m pool elevation (left) and 9 August 2010 at 76 m pool elevation (right).

Mudflats are undesirable for various reasons. First, at low water levels they can detract from site attractiveness, influencing participation levels over a broad spectrum of recreation activities. Second, mudflats promote erosion and contribute to reservoir turbidity and siltation as wind-induced waves resuspend benthic sediment, hit against soft mudflat banks during winter low waters and as heavy precipitation falls over soft unprotected soils. Third, barren mudflats limit biological productivity at various levels, including development of healthy fish assemblages and fisheries.

To improve fish habitat in mudflats biologists have investigated the efficacy of seeding barren shorelines with monocultures of annual terrestrial grasses. A limited number of efforts have suggested that seeding exposed shorelines with annual terrestrial grasses can produce lush stands of vegetation that depending on latitude can grow through fall and winter (Strange et al. 1982; Ratcliff et al. 2009). However, seeding the vegetation often does not persist once inundated, and in some cases it may not last long enough to produce the desired benefits. Moreover, applicability of this management practice has been limited by the difficulties associated with distributing seeds over exposed mudflats.

Project Objectives

1. Assess growth of agricultural plantings on reservoir mudflats
2. Assess persistence of agricultural plantings following inundation
3. Evaluate the benefit of agricultural plantings on reservoir mudflats to juvenile gamefish growth and abundance
4. Evaluate the benefit of agricultural plantings on reservoir mudflats fish communities

Study Area

This study is being conducted on Enid Lake in Northwest Mississippi. This study occurred in an embayment, Long Branch Creek, of Enid Reservoir in Northwest Mississippi. Enid Reservoir encompasses a conservation pool surface area of over 6,500 ha in Yalobusha, Panola, and Lafayette counties, Mississippi formed by the impoundment of the Yocona River. This reservoir was impounded in 1952 as part of the U.S. Army Corps of Engineers Yazoo Headwater Project, with the aim of preventing flooding in the Mississippi Delta region in western Mississippi.

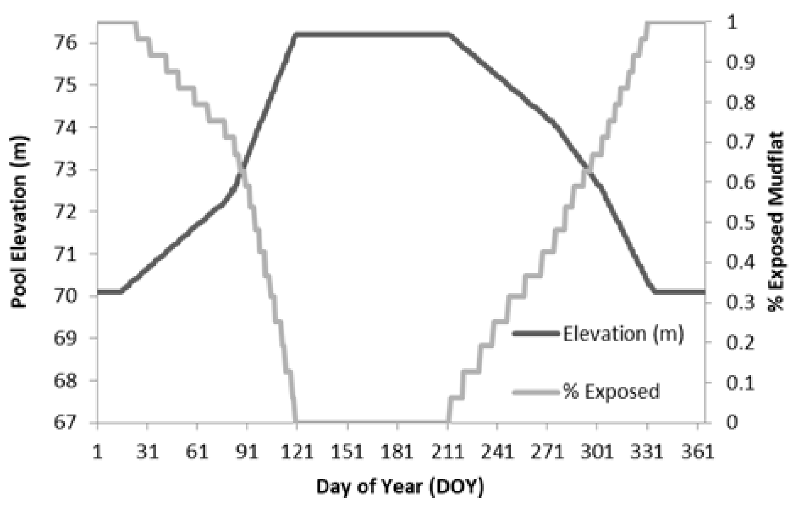

Figure 2. Enid Reservoir guide curve and % exposed mudflats. Enid Reservoir pool elevation in meters (left y-axis) and % exposed mudflat (right y-axis) plotted against day of the year.

The water level of Enid Reservoir varies seasonally but generally follows a guide curve created by the U.S. Army Corps of Engineers. The guide curve (Figure 2) provides a target pool elevation level for each day of the year. The guide curve suggests that in a normal year the reservoir fluctuates 6.1 m, which results in a change in area of approximately 4,000 ha (i.e., from 2,476 ha at 70.1 m elevation to 6,527 ha at 76.2 m elevation; Figure 2). These temporal changes in water level interact with seasonal temperature changes to influence the extent of mudflats exposure, time of exposure, and at what temperature conditions. Thus, the 74-76 m contour region, for example, encompasses an area of approximately 1,700 ha that is de-watered for an average of 225 days per year (Figure 3), and during a period when temperatures average 13.7° C (Figure 4). In contrast, the 71-72 m contour region encompasses an area of approximately 500 ha, is exposed for an average of 104 days per year (Figure 3), with an average temperature of 6.7° C (Figure 4). Because the first frost usually occurs in late October, the 74-76 m contour is exposed for approximately 50 frost-free days in the fall, whereas the 71-72 m contour is exposed for 0 frost-free days (Figure 5).

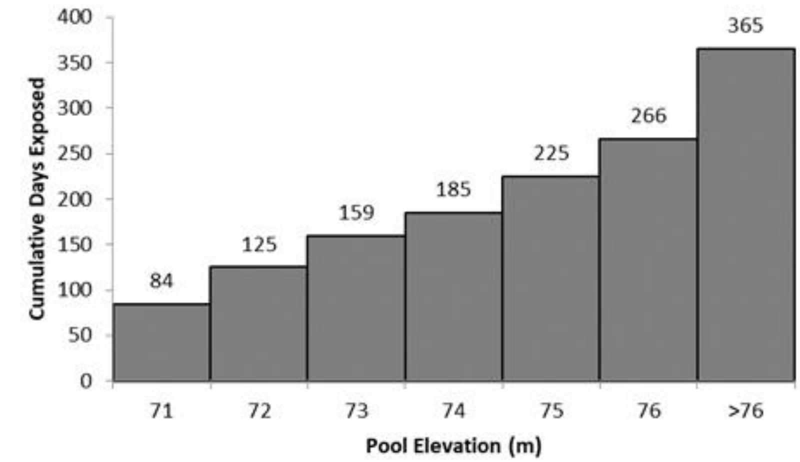

Figure 3. Enid Reservoir days of exposure based on pool elevation (m). Cumulative days of exposure per year relative to pool elevations in Enid Reservoir, Mississippi.

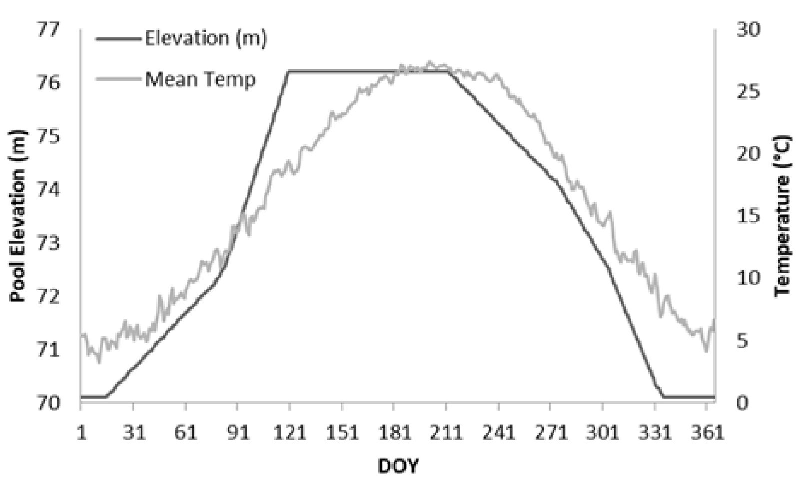

Figure 4. Enid Reservoir guide curve relative to mean daily temperature and day of year. Pool elevation in m (left y-axis) at Enid Reservoir, Mississippi, and mean daily temperature in °C at Batesville, Mississippi (right y-axis) plotted against day of year (DOY).

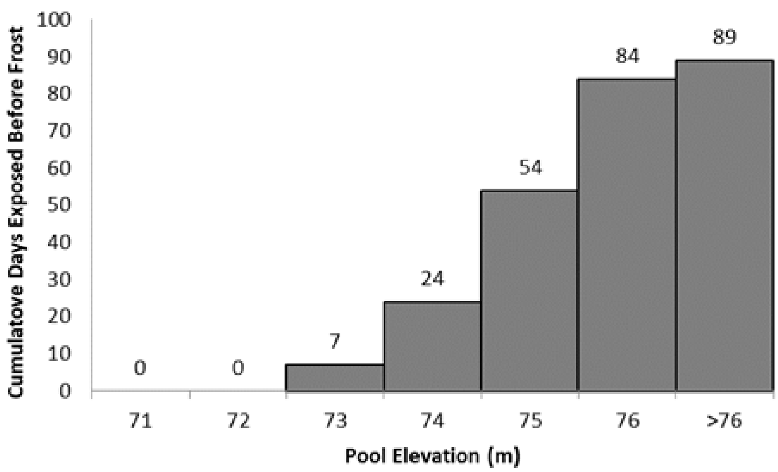

Figure 5. Enid Reservoir average frost-free exposure days by pool elevation (m). Average cumulative days of mudflat exposure before first frost at Enid Reservoir, Mississippi. On average, first frost occurs on 28 October (day of year 301).

Growth and Establishment of Agricultural Plantings on Reservoir Mudflats: Progress

Experimental Design Year 1

We planted experimental agricultural plots in Long Branch Creek during the first two weeks of October 2016. A total of 35 plots of 0.5 ha each were established between 74 and 76 m pool elevation levels. A stratified systematic design was used such that a single randomly assigned sequence of treatments was created and assigned to plots spatially. Treatments included 4 monoculture plantings, 2 mixed plantings, and an unplanted control. Marshall Ryegrass (*Lolium*), Triticale (x *Triticosecale* sp.), Balansa Clover (*Trifolium michelianum*), and Frosty Berseem Clover (*Trifolium alexandrinum*) made up the monoculture plantings. Mixed plantings consisted of a Rye Grass and Balansa Clover mix or Triticale and Balansa Clover mix at a 30% grass to 70% clover seeding rate.

Plots were seeded using rates prescribed by manufacturers (Table 1). Typically, in wildlife food plot applications seeding rates are adjusted for pure live seed (PLS) based on pure live seed and germination rates provided by manufacturers (Eq. 1.1).

$$\text{PLS adjusted rate} = \frac{\text{Recommended Seeding Rate}}{\text{\% Germination} * \text{\% Live Seed}} \qquad (1)$$

Table 1. Seeding rates for agricultural plantings sown at Enid Reservoir during October 2016 and 2017. Species planted with manufacturer suggested seeding rate in kilograms per hectare, cost per hectare for manufacturer suggested rates, and pure live seed adjusted seeding rates.

Common Name	**Manufacturer**	**kg/ha**	**cost/ha (US$)**	**adj kg/ha**
Triticale	Buck Island Seed Company	140	200	168
Nelson Ryegrass	The Wax Company	28	25	33
Marshall Ryegrass	The Wax Company	39	50	46
Berseem Clover	Grassland Oregon	28	350	52
Balansa Clover	Grassland Oregon	18	100	40

Figure 1. Seeding mudflats in fall at Enid Lake with an all-terrain vehicle and a food plot implement.

We elected to use unadjusted manufacturer suggested seeding rates to reduce costs. We planted plots using two planting implements, a Plotmaster Hunter 300 and a Plotmaster Hunter 400 both pulled behind Honda Foreman 500 ATVs (Figure 1). The planting implements each have disking, spreading, dragging, and culti-packing capabilities. Seeding implements were calibrated prior to plantings, by seeding small areas of known size with specified seed amounts and adjusting seeder settings, to ensure proper dispersion of seed throughout the planted area. Control plots were disked but were not seeded so that soil disturbance was not a confounding variable when comparing treatments to control plots. All plots had two 1 m^2 exclosures constructed from 5 cm mesh poultry wire placed randomly within the plots to evaluate the impacts of herbivory on growth (Lashley et al. 2011).

Soil tests were conducted for each of the 35 experimental plots to quantify nutrients and composition. A total of 10 samples of the top 15 cm of soil were collected in each plot with a shovel, combined in a 19-liter bucket, bagged, and labeled. Samples were analyzed by the Mississippi State University Extension Service soil lab. Soil tests provide accurate estimates for soil pH, macronutrients (Phosphorus and Potassium), micronutrients (Calcium, Magnesium, Zinc, and Sodium), and cation exchange capacity (CEC) which all influence plant growth. Soil pH readings are calculated using a standard commercially available pH meter on a soil water suspension, with a precision of +/- 0.1 - 0.3 pH units. Soil nutrient levels are calculated using the Mississippi Soil Testing method described by Lancaster (1970). The Mississippi Soil Testing method is calibrated such that repeated tests of standard soil samples yield a coefficient of variation of 5 to 10 percent within samples.

Sampling Design Year 1

Growth of experimental agricultural plantings was monitored monthly from one month after planting (November 2016) through Late Winter (Early March 2017) and a bi-monthly basis from Early Spring (Mid-March 2017) through Late Spring (Mid-May 2017). Several growth variables were evaluated including ground coverage, height, monthly and full-season dry biomass production, and stem density. All experimental plots were evaluated, with each sown plot evaluated for the species planted and control plots evaluated for naturally growing species.

Point intercept sampling allowed for analysis and comparison of ground coverage, plot composition, and height between sown species (Caratti 2006). Three transects each 30 meters in length were randomly assigned extending from the midpoint of each plot (Figure 2). Along these transects a pole, consisting of a piece of rebar 31 mm in diameter, was used to evaluate ground cover every 1 m. At each point the types of plants intersecting the pole was recorded. Height of sown plants where plants intersected sampling points along the transect was recorded to the nearest 1 cm.

We collected biomass clippings from sown species for analysis of dry weight. Clippings were taken from 1-m^2 exclosures randomly distributed in the plot (Figure 2). One exclosure was clipped during every sampling event from November to mid-April and moved to a new randomly selected location within the plot. The other exclosure remained in the same location from November until the time it was clipped in mid-April. Samples were then dried in an oven with weights recorded every 12 hours until weights stabilized to within +/- 0.5g (Lashley et al. 2014). Annual and monthly biomass clippings were used to estimate dry biomass production for each plot. A comparison of season-long clippings to final-month clippings allowed for the evaluation of the potential impact of herbivory on establishment.

Stem density of sown species were recorded inside of monthly biomass exclosures as well as within a randomly selected 1 m^2 area outside of exclosures. The use of measurements both within and outside of exclosures accounted for the potential impact of herbivory on stem density counts.

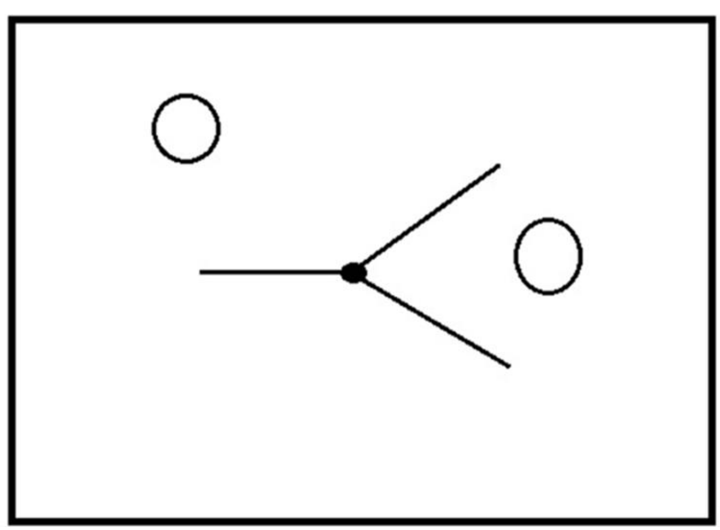

Figure 2. Growth sampling design used at Enid Reservoir during the 2016-2017 and 2017-2018 growing seasons.

Experimental Design Year 2

Experimental agricultural plots were again sown in Long Branch Creek in October 2017. A total of 40 plots of 0.125 ha each were randomly assigned between 74 and 76 m pool elevation levels. Treatments included 5 monoculture plantings, 2 mixed plantings, and an unplanted control. Marshall Ryegrass, Nelson Ryegrass (*Lolium multiflorum*), Triticale, Balansa Clover, and Frosty Berseem Clover made up the monoculture plantings. Mixed plantings consisted of a Marshall Ryegrass and Balansa Clover mix at a 30% grass to 70% clover seeding rate, and a Nelson Ryegrass and Triticale mix at a 50% each seeding rate. Control plots received disking using planting implements but were not seeded.

All plot areas were mowed at least one week prior to seeding using a 1.5 m bush hog and a 60-horsepower tractor. Mowing removed warm season growth which occurred throughout the prior growing season because of lower than normal pool elevation levels. All mowing was conducted from 11-13 October with approximately one week allowed between mowing and planting. Plots were seeded using the same equipment and methods as those used during the 2016 planting season. Soil tests were collected for each of the 40 experimental plots. A total of 10 samples of the top 15 cm of soil were collected in each plot using a shovel and combined in a 19-liter bucket and bagged and labeled. Samples were analyzed through the Mississippi State University Extension Service soil lab.

Sampling Design Year 2

Growth of agricultural plantings was monitored monthly from two months after planting (December 2017) through inundation (February 2018). Growth evaluations were conducted using the same methods as evaluations from the 2016-2017 growing season.

Unexpected Obstacles

Abnormally low pool levels during most of 2017 allowed warm-season plants to flourish throughout the growing season at the upper levels of mudflats. Since 1953 Enid Reservoir has failed to reach its full pool level in 12 years, or about 20% of the time.

Abnormally high pool levels during the winter of 2018 prematurely inundated plots approximately two months ahead of guide curve estimates. Premature inundation prevented plantings from achieving full growth potential. Therefore, metrics such as height of growth and biomass which depended upon plants reaching full maturity were excluded from analysis for the 2017-2018 growing season.

Data Analysis

To characterize the productivity of soils within the mudflats of Enid Reservoir we compared mean, median, minimum, and maximum values for pH and macronutrients (Phosphorus and Potassium; kg/ha) obtained from soil tests for all plots from each growing season to target values for agricultural plantings (Harper 2008). These comparisons provided a frame of reference to characterize soil productivity.

To evaluate successful establishment of plantings we conducted an analysis of variance (ANOVA) to test if differences existed in ground cover and in stem density among planting treatments. We selected these metrics because we deemed them effective indicators of successful establishment and representative of the density and prevalence of planted species within plots. When differences were detected by ANOVA, Tukey's Honest Significant Difference (HSD) post-hoc test was used to compare between individual species. We used data from both the 2016-2017 and 2017-2018 growing seasons for evaluations of successful establishment. Analysis was conducted for the last sampling event in 2017 and 2018 (May and January respectively) in each year independently. We deemed establishment successful when stem density or ground cover of plantings were larger than in control plots (α=0.05, one tailed).

To evaluate successful creation of cover for fish using plantings we selected growth metrics which we deemed to be relevant for providing effective cover for fish based on existing literature for other forms of supplemental habitat. The first metric we selected was height, which has been shown to be an important predictor for fish abundance around supplemental habitat (Gratwicke and Speight 2005). The second metric selected was stem density, which has been shown to impact fish habitat use in aquatic vegetation (Savino and Stein 1989; Savino and Stein 1992). We conducted ANOVA to test if differences existed between height of growth and stem density of plantings. When differences were detected by ANOVA, Tukey's HSD post-hoc test was used to compare between individual species. We used only data from the 2016-2017 growing season for evaluating creation of cover for fish, as evaluations were limited during the 2017-2018 growing season. Analysis was conducted for the final sampling event of the growing season (May). We deemed creation of cover for fish successful when stem density and height of plantings was significantly larger (α=0.05, one tailed) than control plots.

Results

Soil Chemistry

Comparisons of soil test results from both planting seasons for pH and macronutrients with target values showed poor soil productivity in the mudflats of Enid Reservoir (Table 2). The mean and median values for each metric from both planting seasons fell short of target pH and macronutrients levels for the planted species during both growing seasons. Additionally,

Table 2 Soil chemistry levels in the mudflats of Long Branch embayment in Enid Reservoir, Mississippi, 2016-2017 and 2017-2018. Values for mean, median, minimum, and maximums for relevant soil metrics provided by soil tests for both growing seasons. A total of 35 plots were included in 2016-2017 samples and a total of 40 plots were included in 2017-2018 samples. Target values for pH and macronutrient levels are provided (Harper 2008), target levels for secondary and micronutrients are excluded as they vary greatly based on the species planted as well as regionally. (pH=soil acidity, P=Phosphorus, K= Potassium).

Soil Metric	2016-2017				2017-2018				Target
	Mean	Median	Min	Max	Mean	Median	Min	Max	
pH	4.8	4.8	4.2	5.3	4.9	4.9	4.4	5.6	6.1-6.5
P (kg/ha)	25.0	23.5	6.7	79.6	30.7	30.8	11.2	56.0	35-135
K (kg/ha)	88.5	95.3	29.1	151.3	134.5	130.0	28.0	273.5	180-360

maximum observed values from all plots for pH during both planting seasons and phosphorus during the 2016-2017 planting season fell short of target ranges.

Figure 3. A ryegrass plot in spring several months after planting in fall.

Vegetation Establishment

Analysis of variance revealed significant differences among treatments with respect to growth metrics indicative of vegetation establishment. Stem density varied among treatments for the 2016-2017 growing season (P<0.01). Marshall Ryegrass stem densities were greater than control plots but Balansa Clover and Berseem Clover had lower stem density than control plots (Figure 3, 4). Stem density also varied among treatments in 2017-2018 (P<0.01), but no treatments differed from control plots (Figure 5). Plant coverage varied among treatments for the 2016-2017 growing season (P<0.01). Marshall Ryegrass had greater coverage than control plots but Berseem clover had lower percent coverage than control plots (Figure 6). Plant coverage varied among planting

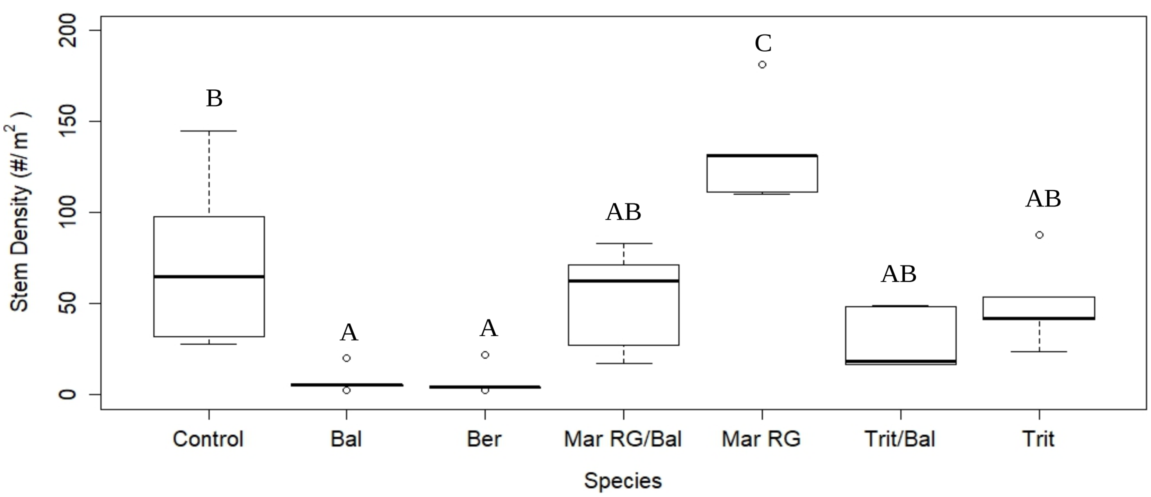

Figure 4. Stem density for planted species in the mudflats of Long Branch embayment in Enid Reservoir, Mississippi 2016-2017.

treatments for the 2017-2018 growing season (P<0.01) as well. Control plots plant coverage was higher than all treatments for the 2017-2018 growing season. Triticale and Triticale and Nelson Ryegrass mixed plantings performed the best of all species planted in 2017-2018 (Figure 7).

Providing Cover for Fish

Analysis of variance revealed significant differences between treatments with respect to growth metrics indicative of creation of cover for fish. Stem density varied among treatments for the 2016-2017 growing season (P<0.01). Marshall Ryegrass performed best in terms of stem density (Figure 4). Height of growth varied among treatments for the 2016-2017 growing season (P<0.01). Marshall Ryegrass, Triticale, Marshall Ryegrass and Balansa Clover mixed planting, and Triticale and Balansa Clover mixed planting all performed well in terms of height growth relative to control plots (Figure 8).

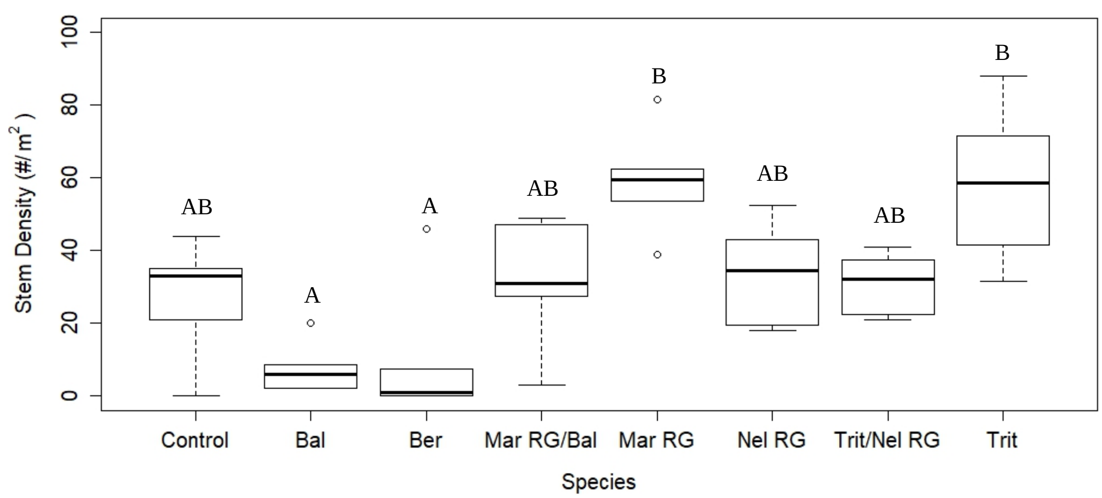

Figure 5. Stem density for planted species in the mudflats of Long Branch embayment in Enid Reservoir, Mississippi 2017-2018. Stem density in stems per m^2 for May growth samples from the 2017-2018 growing season by species with letters representing significant differences from Tukey HSD post-hoc test. A total of 40 plots were included in 2017-2018 samples. (Bal=Balansa Clover, Ber=Berseem Clover, Mar RG/Bal= Marshall Ryegrass / Balansa Clover mixed planting, Mar RG= Marshall Ryegrass, Nel RG= Nelson Ryegrass, Trit/Nel RG=Triticale / Nelson Ryegrass mixed planting, Trit=Triticale).

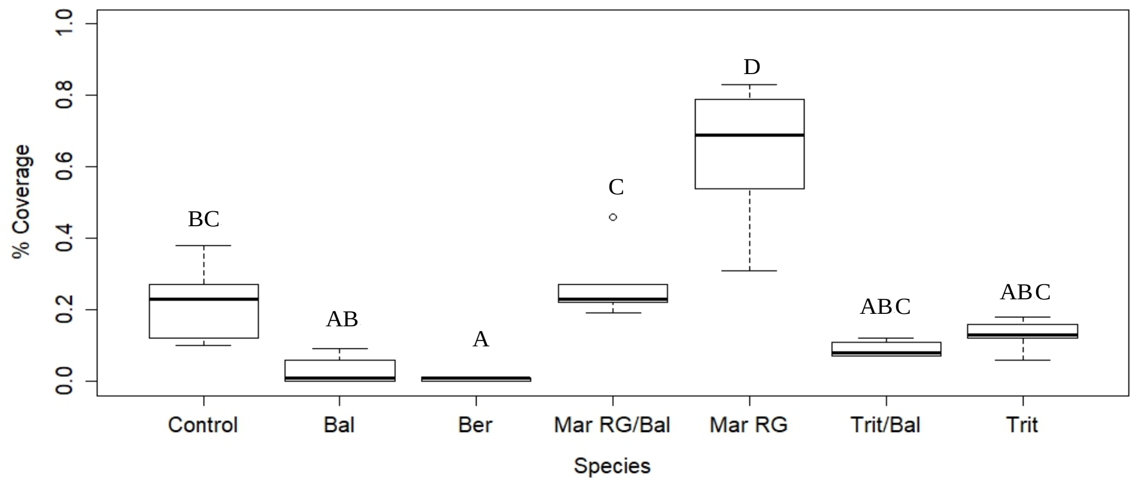

Figure 6. Percent Coverage for planted species in the mudflats of Long Branch embayment in Enid Reservoir, Mississippi 2016-2017. Percent coverage from point intercept sampling for May growth samples from the 2016-2017 growing season by species with letters representing significant differences from Tukey HSD post-hoc test. A total of 35 plots were included in 2016-2017 samples (Bal=Balansa Clover, Ber=Berseem Clover, Mar RG/Bal= Marshall Ryegrass / Balansa Clover mixed planting, Mar RG= Marshall Ryegrass, Trit/Bal=Triticale / Balansa Clover mixed planting, Trit=Triticale).

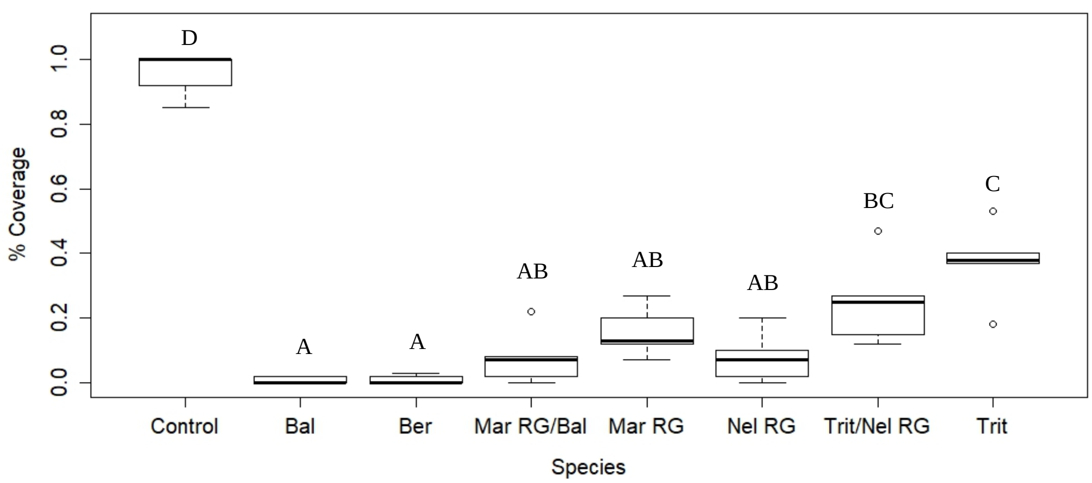

Figure 7. Percent Coverage for planted species in the mudflats of Long Branch embayment in Enid Reservoir, Mississippi 2017-2018. Percent coverage from point intercept sampling for February growth samples from the 2017-2018 growing season by species with letters representing significant differences from Tukey HSD post-hoc test. A total of 40 plots were included in 2017-2018 samples. (Bal=Balansa Clover, Ber=Berseem Clover, Mar RG/Bal= Marshall Ryegrass / Balansa Clover mixed planting, Mar RG= Marshall Ryegrass, Nel RG= Nelson Ryegrass, Trit/Nel RG=Triticale / Nelson Ryegrass mixed planting, Trit=Triticale).

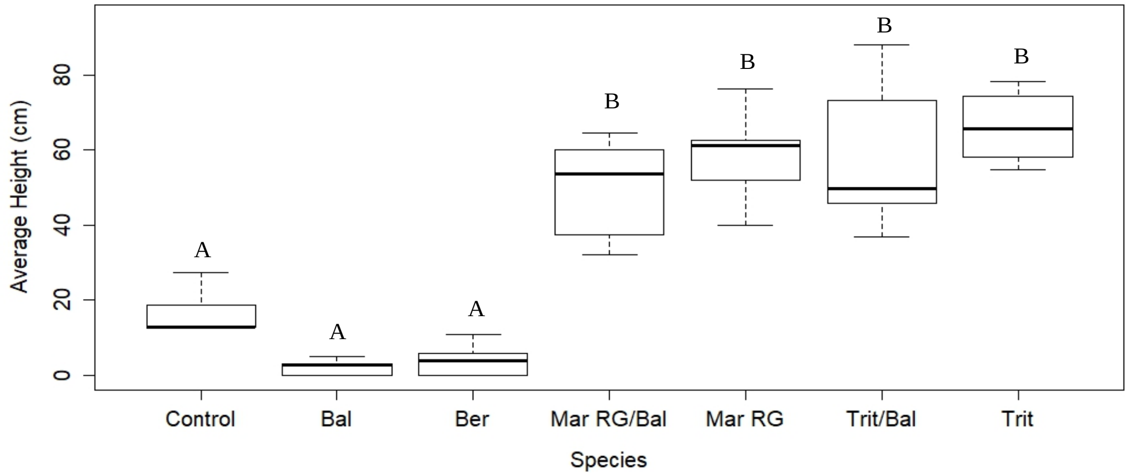

Figure 8. Height for planted species in the mudflats of Long Branch embayment in Enid Reservoir, Mississippi 2016-2017. Average height in cm for May growth samples from the 2016-2017 growing season by species with letters representing significant differences from Tukey HSD post-hoc test. A total of 35 plots were included in 2016-2017 samples (Bal=Balansa Clover, Ber=Berseem Clover, Mar RG/Bal= Marshall Ryegrass / Balansa Clover mixed planting, Mar RG= Marshall Ryegrass, Trit/Bal=Triticale / Balansa Clover mixed planting, Trit=Triticale).

Discussion

Over a period of two years we planted approximately 20 ha of agricultural plantings consisting of a total of 5 agricultural species in the regulated zone of Enid Reservoir. This study provides one of the most thorough evaluations of growth of agricultural plantings within the regulated zone of a reservoir. Previous studies conducted limited evaluations of growth metrics of plantings only reporting average height and occasionally stem density (Strange et al. 1982; Ratcliff et al. 2009). Other studies also planted considerably less area and did so using fertilizer to improve growth, at a greater expense. Our findings indicate that agricultural plantings can be successfully established in the regulated zone of reservoirs without the use of fertilizers and potentially provide effective cover for fish when inundated.

Soil productivity was poor within planted sites on the mudflats of Enid Reservoir during both growing seasons. Low pH and macronutrient levels in regulated zone soils of Enid Reservoir are at a level which likely limits growth and prevents the establishment of species which exhibit limited tolerance ranges (Harper 2008).

Marshall Ryegrass successfully established on the mudflats of Enid Reservoir during the 2016-2017 growing season. Results from the 2017-2018 growing season showed no successful establishment of any species, likely resulting from the shortened evaluation season and the persistence of natural growth from the previous growing season. The attempt to mow and remove existing growth greatly reduced natural vegetation but still left approximately 8 cm of growth above the seedbed. Abundant Korean Lespedeza (*Kummerowia striata*) likely created artificially high coverage and height values for control plots while also diminishing detection of planted species in treatment sites. The successful establishment of Ryegrass during the 2016-2017 planting season is not surprising given the tolerance of the species for wide pH ranges, poor soil fertility, and poor drainage (Harper 2008).

Marshall Ryegrass provided potentially effective cover for fish in terms of stem density and height. Triticale, Marshall Ryegrass and Balansa Clover mix, and Triticale and Balansa Clover mix exhibited effective cover for fish in terms of height. These results indicate that Marshall Ryegrass provides the best option for creating cover for fish, with minimal costs for seed and no fertilizer use. Nevertheless, these conclusions depend on the effectiveness of our selected growth metrics, stem density and height, as indicators of potential fish use. The greatest average height among planted species was observed in Triticale, which suggests a mix between Ryegrass and Triticale may potentially optimize both height and stem density. During the 2017-2018 growing season a mix between Nelson Ryegrass and Triticale was sown in experimental plots, but the brief duration of the season limited comprehensive evaluation of establishment and effectiveness.

Agricultural plantings have long been considered a means of providing cover for fish in the regulated zone of reservoirs. However, evaluations of their effectiveness have been limited, with only two published comprehensive studies to date (Strange et al. 1982; Ratcliff et al. 2009) and two other less detailed evaluations (Hulsey 1959; Groen and Schroeder 1978). Our findings provide evidence that agricultural plantings can be established in the regulated zones of reservoirs without the use of fertilizers. Furthermore, based on available information in the literature and observed growth, several of our planted species appear to provide effective structure to potentially serve as beneficial fish cover for fish. Our results strongly support the use of Ryegrass planting as a viable form of supplemental fish habitat. Species like Triticale also hold promise as beneficial cover for fish. The importance of selecting cool season species with tolerances for poor growing conditions cannot be over stated. Clover species seeded in this study exhibited poor establishment, likely resulting from poor soil productivity and limited rainfall immediately following plantings. Similarly, Strange et al. (1982) observed failures of large areas of cultivated regulated zones due to poor fertility and variable precipitation.

Lessons learned extend beyond plant selection and into the planning process. Planting in years following below-average reservoir pool levels is likely a waste of resources. Below average pool levels during the 2016-2017 growing season allowed for ample natural plant growth which would have likely reduced the benefit of our plantings. Additionally, areas had to be mowed in preparation for plantings, creating an added expense in both time and resources. Moreover, in practical applications wider contour ranges may need to be sown to ensure plantings are inundated and available for fish use during critical periods given variability in pool levels. Our plantings focused on a narrow 2 m contour interval (74-76 m) for the purposes of facilitating a more robust experimental design. Furthermore, managers wishing to apply agricultural plantings should consider costs of seed relative to production when selecting species. Additionally, seeding rates could be adjusted based on pure live seed (Equation 1,

Table 1) to improve germination and growth in applications where costs are not prohibitive. Our inability to evaluate plots due to variability in inundation timing highlights not only the need to sow wide contour ranges but also the need to select candidate reservoirs with predictable water regimes. The ability to effectively predict pool level fluctuations serves as an important requirement to effectively implement agricultural plantings to provide supplemental fish habitat. Future research should focus on reservoirs with more predictable pool levels or effectively quantifying pool predictability to inform decision making by fisheries managers.

Fisheries managers will continue to search for efficient methods to prevent the habitat homogenization occurring in aging reservoirs around the nation. Supplemental agricultural plantings may have a prominent role moving forward in combating diminished productivity in reservoirs. Lessons learned from past studies highlight the limitations associated with this method, however the potential for benefits to fish communities at low costs to management agencies warrants further investigation.

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Submergence response of cool-season annual crops and their performance as potential fish habitat: Progress

Reservoirs that experience annual winter drawdowns create harsh unnatural conditions in shallow areas. As water levels fluctuate, the littoral zone moves across sections of shorelines known as the regulation zone. Lake substrates in the regulation zone are exposed and desiccated during drawdowns, which can leach nutrients once flooded (Cooke 1980). Grain size, water content, and density of soils in the regulation zone can be significantly altered by drawdowns but vary depending on water regime and geomorphology of the reservoir bottom (Carmignani and Roy 2017). Littoral water clarity is usually low due to excessive suspended inorganic particles from shoreline erosion and sediment mobilization (Furey et al. 2009). At low lake levels, such as those produced by periodic drawdowns, deposited sediment can be resuspended into the water column. Winter drawdowns are required to fulfill the operational objective of many impoundments but have deleterious effects on abiotic components of littoral ecosystems.

Conditions in the regulation zone alter and limit plant and invertebrate communities. Consistent annual drawdowns limit the establishment of hydrophytes (Beard 1973; Goldsby and Sanders 1977). Flood intolerant terrestrial vegetation recolonize shorelines during exposure, however winter temperatures limit net growth and seasonal die-offs during spring flooding turn littoral habitats into barren mudflats (Miranda 2017). Periphyton community composition varies with depth and biovolume can decrease with increasing exposure probabilities (Cantonati et al. 2009). Species richness and density of benthic macroinvertebrates decline in zones experiencing water level fluctuations (Kraft 1988; Brauns et al. 2008, Haxton and Findlay 2008). Macroinvertebrate communities become represented by mobile taxa that can escape decreasing water levels. These combined effects result in poor habitat and forage for higher trophic levels.

Reservoir mudflats negatively affect reproduction and young of the year survival of associated fish assemblages. Water elevations and water level fluctuations can indirectly affect reproductive success and year class strength by varying the quality and quantity of spawning habitat available (Zohary and Ostrovsky 2011). Varying water levels can cause egg desiccation if nests are exposed (Sutela et al. 2002). High sediment loads in the regulation zone can cause egg mortality if sediment deposits on eggs leading to suffocation (Hassler 1970). Varying water levels can also cause mortality of juvenile fishes if they are stranded on mudflats (Heman et al. 1969). Juvenile fishes typically congregate near submerged vegetation in the littoral zone to escape predation (Hall and Werner 1977). The lack of vegetation in reservoir mudflats can lead to heightened predation of juvenile fish (Ploskey 1983).

Adequate terrestrial vegetation in the regulation zone of drawdown reservoirs can benefit fish assemblages. Vegetation can be provided via direct manipulation of water elevations or through enhancement of plant communities. Above average water levels that flooded upland plants increased abundances of age-0 fishes (Shirley and Andrews 1977; Miranda et al. 1984; Kahl et al. 2008). Increasing frost-free exposure time of the regulation zone can enhance natural growth of terrestrial plants. Upon inundation, increases in age-0 fish growth (Kaczka and Miranda 2014) and abundance (Martin et al. 1981; Meals and Miranda 1991) have been documented. Manipulating water levels is a powerful tool for reservoir managers, however the operational objective of reservoirs usually requires adherence to predetermined elevations for every day of the year. The second method of improving access to plants is to manipulate and enhance the plant community in the regulation zone during winter drawdowns. Fast growing cool-season agricultural plants can be planted on mudflats once they are exposed in autumn, and the plants grow until inundation in the spring (Miranda 2017). This method has been used for nutrient additions and turbidity reductions (Hulsey 1959) as well as to improve black bass recruitment (Strange et al. 1982; Ratcliff et al. 2009). Earlier studies have tested a few plant species, but overall observations about individual plant performance are limited. Additional information is required to select appropriate plants for mudflat enhancement.

Submerged performance of agricultural plants is paramount to reservoir mudflat applications. Ratcliff et al. (2009) planted Cereal Barley (*Hordeum vulgare*) that persisted poorly once inundated. They found that black bass abundances were significantly greater in an artificial plant bed made of polypropylene rope than in seeded areas and attributed the difference to the lower structural persistence of plantings. The study identified a need for more information on the longevity of different crops to select an appropriate species for mudflat enhancement. There is an abundance of literature analyzing submerged crop performance in relation to forage quality and tolerance (Ashraf 2012; Tamang and Fukao 2015). Generally, these studies minimally submerged plants and for short durations. To analyze crops for mudflat applications, information is required on the fate of vegetative structures entirely submerged during a period similar to that experienced in mudflats. Additionally, observations of the structural complexity of plants would offer valuable information on what types of fish each plant would benefit the most.

The purpose of this study was to evaluate under controlled laboratory conditions the response of various agricultural plants to submergence and to assess their performance as potential fish habitat. Specifically, the objectives of this study were to: 1) determine how long submerged mudflat plantings would need to persist in a reservoir to provide effective fish habitat; 2) determine in a laboratory setting the length of time plants will persist as suitable fish habitat; and 3) describe in a laboratory setting the structural complexity of plants over time. I hypothesized that lignin and fiber concentrations of plants were positively associated with persistence of height and complexity. I also hypothesized that grasses generally persisted longer than forbs.

Methods

Required Persistence Interval

Temporal characteristics of fish habitat use in flood control reservoirs were required to make comparisons to experimental persistence intervals of agricultural plants. I selected Enid Lake, located in northern Mississippi, to serve as a model reservoir and to estimate the required persistence interval. The U.S. Army Corps of Engineers manages the reservoir with the primary purpose of flood control and targets a winter drawdown of 6 m annually (Figure 1). Shallow areas of the reservoir are degraded and littoral fish assemblages are limited to mudflats when water level returns to normal elevation (Meals and Miranda 1991). To determine the target planting elevation contour of shoreline, observations of exposed soils were made in September and October of 2016 at a suitable planting site. The target planting contour was selected based on rate and timing of exposure, rate of soil desiccation, and shoreline gradient. The required persistence interval was defined as the length of time from when the target planting contour became completely submerged until when juvenile fish began abandoning submerged structure in reservoir mudflats.

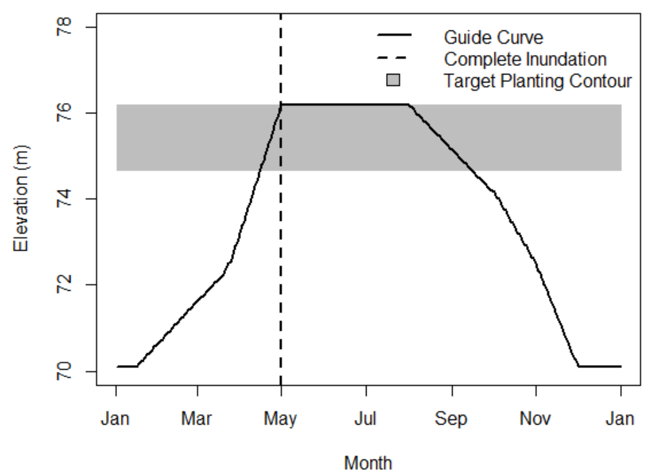

Figure 1. The guide curve of Enid Lake, MS, established by the U.S. Army Corps of Engineers to manage water levels. Additionally, the elevations of exposed lake bottom in the target planting contour with its date of complete inundation.

To determine the use of refuge by juvenile fish in the mudflats of Enid Lake, we sampled fish congregating near man-made brush piles from May to September 2017. A total of 57 randomly selected brush piles were sampled every 2 weeks at a mean depth of 0.8 m (sd = 0.2). A block-net was used to enclose the area within 5 m of brush piles and lethal doses of rotenone were applied inside the enclosure. Fish were collected, identified, and measured to total length.

Plant Selection

Crops included in this study (Table 1) were selected based on their ability to: 1) be planted during winter drawdowns and 2) tolerate poor soil conditions. All experimental plants were cool-season annuals which are adapted to germinate during autumn, grow throughout winter,

Table 1. A list of annual crops used in this study with their scientific name, planting season, and soil condition tolerance (Harper 2008, Grassland Oregon 2018).

Cultivar	Scientific Name	Planting Date	Optimal Soil Conditions
Balansa Clover	*Trifolium michelianum*	Sep 15 – Oct 30 (southeastern US)	Sandy to clay; tolerates shade, poor drainage, and moderate salinity; pH: 4.5 – 8
Marshall Ryegrass (diploid)	*Lolium multiflorum*	Aug 15 – Oct 15; Feb 15 – Apr 1	Most textures; tolerates poor drainage; moderate fertility requirements; pH: 5.8 – 6.5
Nelson Ryegrass (tetraploid)			
Oat	*Avena sativa*	Aug 15 – Oct 15; Feb 15 – Mar 15	Sandy to clay; well-drained; pH: 6 – 6.5
Triticale	*Triticale hexploide*	Aug 15 – Oct 15	Sandy to clay; well-drained; pH: 5.8 – 6.5
Wheat	*Triticum aestivum*	Aug 15 – Oct 15	Light-textured; well drained; pH: 6 – 7

and reach maturity during spring. This life history coincides with lake substrate exposure of winder drawdowns. Reservoir mudflat soils experience months of anaerobic conditions annually, which significantly affect microbial processes that can reduce nutrient availability, acidify soils, and increase concentrations of toxic organic compounds and reduced forms of manganese, iron, and sulfur (Cronk and Fennessy 2001). Additionally, soil particle size can vary depending on location in the reservoir and dam operation (Luken and Bezold 2000; Wagner and Falter 2002). In a typical agricultural setting, these issues do not exist or can be alleviated via soil amendments. Due to time constraints imposed by water regimes, mudflat plantings require immediate establishment once exposed with little to no seedbed preparation. Such varying and potentially harsh conditions require robust plant species. Because of this, experimental plants selected represent some of the most tolerant cool-season crops that are readily available for purchase within the United States.

Plant Cultivation

This experiment was performed twice over the course of two years. Each year consisted of a cultivation phase (Autumn - Spring) and a submergence phase (Spring - Summer) with timing and duration corresponding approximately to the target planting contour previously described (Figure 1). Plant cultivation lasted between 2 and 7 months at the MSU Wildlife and Fisheries Research and Educational Facility. Length of growing seasons and replications varied between years and treatments (Table 2) due to autumn cultivation failure that required supplemental plantings during the winter and early spring. A total of 207 pots (15 cm diameter) were filled with locally purchased bagged topsoil, seeded, and fertilized (6:2:1, N-P-K ratio) every two weeks. Cultivar seed germination and purity ratios determined seeding rates. Plants

Table 2. Cultivation duration and quantity of replications of plant treatments by experiment.

Cultivar	Experiment 1		Experiment 2	
	Replicates	Cultivation	Replicates	Cultivation
Balansa Clover	4	Jan - May	12	Feb – May Mar – May
Marshall Ryegrass	8	Oct – May Jan – May	15	Feb – May Mar – May
Nelson Ryegrass			15	Feb – May Mar – May
Oat			15	Feb – May Mar – May
Triticale	8	Oct – May Jan – May	15	Feb – May Mar – May
Wheat			15	Feb – May Mar – May

were housed outdoors beneath a hoop frame structure outfitted with bird netting and were occasionally transported into a greenhouse during freezing temperatures. All plants, except for Balansa Clover, during experiment 1 reached maturity and produced well developed stems supporting seed heads. Conversely, none of the plants in experiment 2 reached maturity and much of the above ground biomass were leaves.

Plant Submergence

The submergence phase lasted for 3 months at the MSU South Farm Aquaculture Facility (May – August, 2017 and 2018). Plants were prepared for flooding by covering exposed soil with a layer of gravel to prevent suspension and fastening bricks to the bottom of pots to reduce buoyancy (Figure 2). Plants were submerged in flow-through fiberglass aquaculture tanks (2.4 m diameter, 1.4 m height) that were outdoors and shaded. For experiment 1, replicates were submerged in 1 tank and randomly assorted approximately 30 cm from the tank wall. For experiment 2, equal replicates of each treatment were randomly assigned to 5 tanks then randomly assorted like experiment 1. Water levels were held constant at 1.2 m and continuously aerated. Water was circulated in an out of the tanks as needed to reduce turbidity and algal growth.

Structural Measurements

Structural measurements were extracted from underwater photographs taken between 1-3 times per week. A Fujifilm FinePix XP70 camera mounted on a PVC rod produced images with a resolution of 16.4 MP. Maximum height (cm) of basally-connected vegetation was measured as the highest vertical distance from pot substrate. Stem density of submerged macrophytes is often used to index habitat complexity and can mediate predator-prey interactions (Crowder and Cooper 1982; Savino and Stein 1982). Thus, structural density (n) was included as an indicator of complexity and was measured by counting all basally connected and independently originating structures. This definition does not differentiate between shoots and leaves due to difficulty distinguishing the structures in photographs. Structures were no longer measured if they disconnected from the basal portion of plants.

Figure 2. Flooding of experimental plants in circular tanks to evaluate persistence after inundation.

Statistical Analyses

Required persistence interval. – Dates of maximum relative abundance of juvenile Largemouth Bass (*Micropterus salmoides*), Black Crappie (*Pomoxis nigromaculatus*), and White Crappie (*Pomoxis annularis*) were used to determine the required persistence interval. I selected these species because they are often associated with vegetative cover. Fish included in analysis were those with total lengths less than age-0 total lengths defined for the state of Mississippi in Ross et al. (2001). Catch per unit effort (CPUE) indexed relative abundance of game species at brush piles.

Persistence time and probability. – Time-to-event models were used to estimate persistence time of treatments. The event for the model was defined at a maximum height of 0 cm, i.e. when all vertical structure was lost. Persistence times for plant treatments were indexed via Kaplan-Meier estimators of median survival time (Harrell 2015). Effect of year (and thus length of growing season) and plant treatment on the overall probability of reaching an event, hereafter referred to as persistence probability, was tested using log-rank tests.

Structural complexity. – Changes in structural complexity of vegetation over time was characterized using generalized linear models (GLM) (Zuur et al. 2009). Plant replicates that had complete observations for all time intervals were included in models. Quantity of structures for each potted plant served as the interval response variable. Predictors were plant treatment (categorical), submergence-time (continuous), year (categorical), and their interactions. To test the effect of plant treatment and its interaction with time, two separate models were used for each year since treatment levels were unbalanced. Tank did not have a significant effect when included as a categorical predictor and was thus not included in the final model. To test the effect of year (length of growing season), data for plant treatments used in both years (i.e. Balansa Clover, Marshall Ryegrass, and Triticale) were modeled. Poisson distributions were used unless data were overdispersed. To deal with overdispersion, quasi-Poisson models were used in which the mean-variance relationship was defined as the variance being equal to the product of the mean and dispersion parameter.

Results

The target planting contour of reservoir bottom resided in the upper 1.5 m of the guide curve (Figure 1). This contour would be exposed long enough to: 1) dry and become suitable for sowing before the end of the planting season (Harper 2008), and 2) allow for full maturation of cool season crops. The predetermined date of complete inundation was on May 1st. Catch rates of Largemouth Bass, Black Crappie, and White Crappie increased in May, peaked in mid-to-late June, and decreased thereafter. Considering this pattern, I estimated the required persistence interval to be at least 50-60 days (Figure 3).

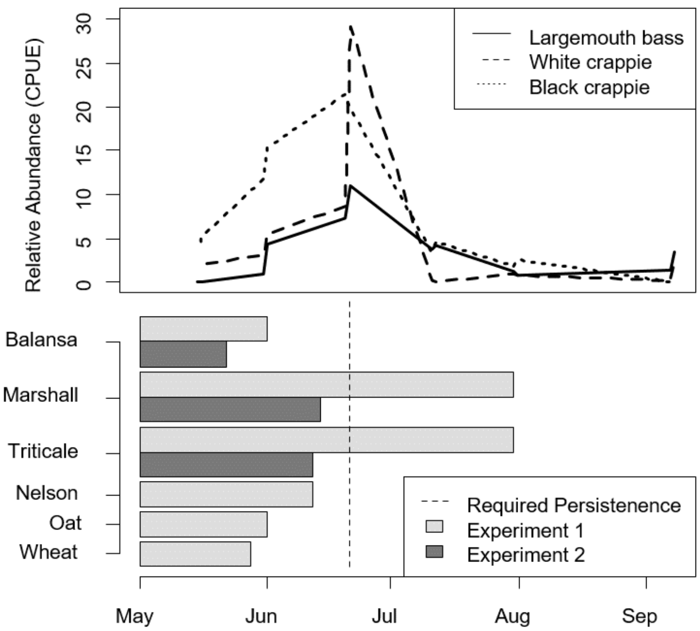

Figure 3. Relative abundances of juvenile Largemouth Bass, Black Crappie, and White Crappie within 5 m of brush pile fish attractors in an embayment of Enid Lake, MS (top). The required persistence interval for agricultural plantings to provide submerged structure for refuge seeking juvenile centrarchids (bottom). Median structural persistence times of submerged agricultural plants during experiment 1 (adult plants) and experiment 2 (juvenile plants) (bottom).

Post-submergence growth was observed during both experiments (Table 3, Figure 4). On average, maximum values for height were realized 5 days (sd = 4.1) and 14 days (sd = 6.4) following inundation for experiments 1 and 2. Experiment 2 Nelson Ryegrass demonstrated the longest period of post submergence growth ($\bar{x}$ = 19 days, sd = 6.7) and experiment 1 Triticale the shortest ($\bar{x}$ = 3 days, se = 5.1). Marshall Ryegrass elongated the most during both experiments and Triticale the least during experiment 1. All plants other than Marshall and Nelson Ryegrass had minimal growth during the second experiment. An analysis of variance (ANOVA) suggested that there

Table 3. Median persistence times and growth of submerged agricultural plants.

Cultivar	Experiment 1			Experiment 2		
	Persistence Time (m days)	Growth ($\bar{x}$ cm ± se)	Growth Days ($\bar{x}$ days ± se)	Persistence Time (median days)	Growth ($\bar{x}$ cm ± se)	Growth Days ($\bar{x}$ days ± se)
Balansa Clover	31	5 ± 0.6	6 ± 0.5	21	3 ± 0.8	9 ± 0.9
Marshall Ryegrass	90	7 ± 1.6	6 ± 1.4	44	16 ± 1.5	18 ± 1.4
Nelson Ryegrass				42	14 ± 0.8	19 ± 1.7
Oat				31	3 ± 0.2	10 ± 0.9
Triticale	90	2 ± 1.0	3 ± 1.8	42	3 ± 0.5	13 ± 1.6
Wheat				27	4 ± 0.5	12 ± 1.3

was no difference in plant growth among tanks ($F = 0.41$, $df = 4$, $P = 0.8$) but there was a significant effect of tank on duration of growth ($F = 4$, $df = 4$, $P = 0.004$). Year significantly affected extent of growth ($F = 4$, $df = 1$, $P = 0.049$) and duration ($F = 39.7$, $df = 1$, $P < 0.001$).

Following the post-submergence growth period, maximum height of plants deteriorated. Overall persistence was greater during the first year where 85% (17/20) of plants retained structure until the end of the 90-day submergence period resulting in fixed type I right-censoring (Harrell 2015). Random type I right-censoring occurred during the second experiment due to excessive growth of *Oedogonium* sp. (a filamentous algae) that obstructed visibility and ended observations of 25% (22/87) of plants still retaining structure prior to the end of the experiment. All observable plants in the second experiment did not persist longer than 77 days. An ANOVA indicated no difference among tanks in the persistence of individual plants ($F = 1.8$, $df = 4$, $P = 0.14$).

Marshall Ryegrass and Triticale in experiment 1 were the only treatments with median persistence times greater than the required persistence interval (Figure 3). Marshall Ryegrass, Nelson Ryegrass, and Triticale in experiment 2 were short 6 to 8 days of the required persistence interval. Persistence probability significantly differed between the two experiments ($X^2 = 38.3$, $df = 1$, $P < 0.001$). Plant treatment had a significant effect on the persistence probability for experiment 1 ($X^2 = 15$, $df = 2$, $P < 0.001$) and experiment 2 ($X^2 = 68.7$, $df = 5$,

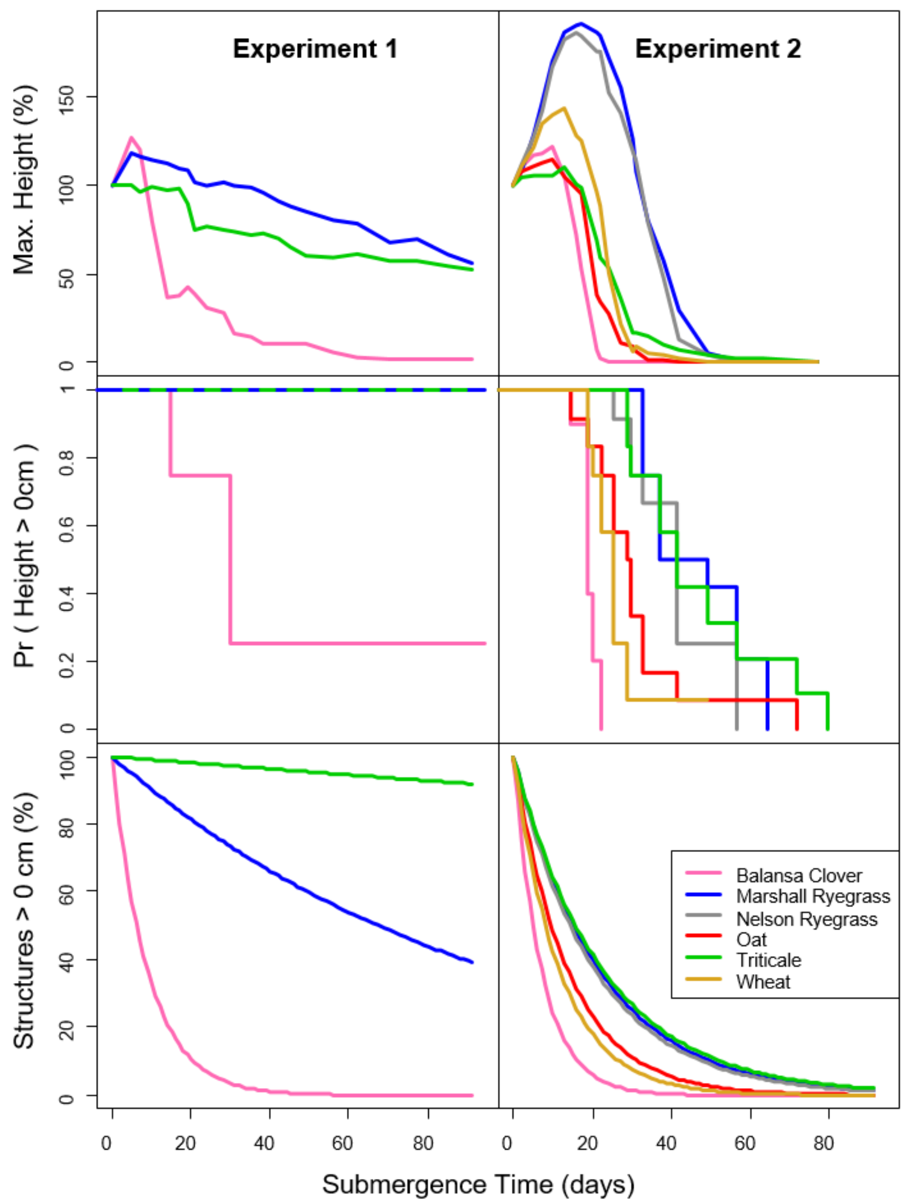

Figure 4. The average percent original maximum height (top) of submerged agricultural plants over time in experiments 1 (left) and 2 (right). Also, the Kaplan-Meier curves of the probability of plants retaining structure > 0 cm for each treatment (center). Finally, the model predictions of structure quantities converted to percent original quantity of structures (bottom).

P < 0.001) (Figure 4). Persistence probability significantly differed when both treatment and year were included as independent variables ($X^2 = 117$, df = 8, P < 0.001). Triticale, Marshall Ryegrass, and Nelson Ryegrass demonstrated the highest median persistence times. Oat and Wheat had moderate persistence times and Balansa Clover the lowest.

Complexity models included all replicates of experiment 1 and 66% (57/87) replicates of experiment 2. Complexity decreased at a significantly higher rate during the second experiment, as indicated by a significant interaction of year and submergence time (quasi-Poisson GLM, dispersion parameter = 2.5, F = 360, df = 2, P < 0.001) (Figure 4). For experiment 1, plant treatments significantly interacted with submergence time (Poisson GLM, Residual Deviance = 466, df = 2, P < 0.001). Triticale and Marshall appeared to have a nearly linear decay of complexity, whereas Balansa Clovers's rapidly reduced. Plant treatments significantly interacted with submergence time for experiment 2 as well (quasi-Poisson, dispersion parameter = 2.8, F = 162, df = 5, P < 0.001). The complexity of all plant treatments rapidly decreased during experiment 2, Balansa Clover decreasing at the fastest rate. Both cultivars of Ryegrass as well as Triticale all had similar rates of decay that were the lowest.

Discussion

Required Persistence Interval and Site Selection

The timing and rate of reservoir bottom exposure determined how much area could be planted and when. The target planting contour at Enid Lake took between 3 and 5 weeks of complete exposure to dry sufficiently. To plant shorelines during suitable temperatures, lake substrates must be exposed early enough to dry and be sown prior to the end of the planting season. Most common cool-season agricultural plants need to be planted by early to mid-autumn (Harper 2008). This means that reservoirs that do not lower water levels in time cannot practice this method or will have poor results if they plant too late and shorten the length of the growing season.

Pre-Submergence Plant Phenological Implications

Differences in the length of growing seasons between years resulted in plants being submerged during different developmental phases. All grasses during experiment 1 were in their reproductive or seed-ripening phases whereas experiment 2 plants were in their vegetative or early-elongation phases (Moore et al. 1991). Balansa Clover replicates, during both experiments, were in the vegetative phase (Kalu and Fick 1980). Two major distinctions between phases of experiment 1 and 2 are the total lignin content of plants and the extent of stem development. Lignin is a complex phenolic polymer synthesized by plants and is used primarily to strengthen cell walls and stiffen structures (Liu et al. 2018). Generally, as monocot grasses (Rancour et al. 2012) and legumes (Bidlack and Buxton 1992; Kratchunov and Naydenov 1995) age their cell wall lignin content increases which strongly reduces degradability (Chen et al. 2002). Additionally, as plants transition from vegetative to reproductive phases, stems elongate and dominate above ground biomass (Moore and Jung 2001). Stems are less metabolically active and more lignified than leaves. For this study, this means that experiment 2 plants were more vulnerable to degradation and had a higher capacity for stem growth than experiment 1 plants. This difference can most notably be seen in the higher growth of Marshall and Nelson Ryegrass during experiment 2 and the increased duration of growth for all plants during that experiment.

Submergence Tolerance

Changes in height of plants following inundation can be an indicator of oxygen deprivation tolerance. For intolerant varieties, critical physiological processes can be interrupted in just a few hours of waterlogged soils, leading to death (Cronk and Fennessy 2001). One tactic of tolerant plants to survive anaerobic conditions is to enter a state of quiescence by ceasing growth, conserving carbohydrates, and regulating harmful biproducts of anaerobic respiration that accumulate in cells (Fukao and Bailey-Serres 2004; Tan et al. 2010). Another common tactic is responding morphologically by modifying or increasing the height of structures to access, transport, or store atmospheric oxygen at the water's surface. For some plants, extent of submergence mediates response tactic (Manzur et al. 2009).

Initial responses of agricultural plants seen in this study are similar to those of other studies of waterlogged soils or short durations of submergence. Biomass of Balansa Clover was nearly unaffected by soils submerged for 35 days and modified its roots for improved oxygen accession and storage (Gibberd et al. 2001). These results, as well as those of this study, suggest that Balansa Clover is highly flood tolerant and capable of modifying both above and below ground structures depending on extent of submergence. Marshall and Nelson Ryegrass demonstrated the highest flood tolerance of experimental species by growing the most and for the longest time. Although the cultivars of annual Ryegrass included in this study appeared to have a heightened ability to tolerate submergence, other annual Ryegrass varieties may not. Yu et al. (2012) and Liu and Jiang (2015) identified highly flood tolerant cultivars of perennial Ryegrass (*L. perenne* L.) and others that were more susceptible. Cereal grains grew poorly in waterlogged soils (Thomson et al. 1992; Watkin et al. 1998), however Oat survived longer durations (Cannell et al. 1985). Cereal grains in this study all responded similarly following submergence with minimal growth of moderate duration.

Persistence

Persistence of plants following growth was most likely indirectly shaped by species biology, phenological differences, and responses to submergence. Generally, legumes and grasses possess similar concentrations of lignin, but legumes have much lower fiber content than grasses making them easier digested and broken down (Moore and Jung 2001). For Balansa Clover, lower fiber concentrations as well as plant immaturity during both experiments could explain why it repeatedly persisted poorly. As previously mentioned, all plants during experiment 2 had a shorter growing season and thus less time to develop lignin than experiment

1. Additionally, it has been shown that post submergence growth of flood-tolerant crops can reduce lignin content of elongating structures (Sauter and Kende 1992). Rapid degradation during experiment 2 was most likely an additive effect of relatively low lignin content of juvenile plants and rapid growth of degradable tissue following inundation.

Persistence of agricultural plants applied on reservoir mudflats is understudied. A summer drawdown of a multi-purpose reservoir, Lake Nottely, GA, enabled mudflat plantings of Sudangrass (*Sorghum bicolor* var. *sudanese*), Sorghum (*S. bicolor*) - Sudangrass hybrid, Fescue (*Festuca* sp.), and Rye (*Secale cereale*) that were flooded for ~ 2.5 months the following year (Strange et al. 1982). Abundances of juvenile fishes were consistently higher in seeded than unseeded areas throughout the submergence period suggesting that plants continued to provide favorable structural habitat until dewatered. Ratcliff et al. (2009) documented persistence of reservoir mudflat plantings of Cereal Barley (*H. vulgare*) in Shasta Lake, CA. After a month of submergence, 85% of height was reduced and 90% of stems fell over and were covered in sediment. The mature grasses of this study persisted longer than Ratcliff et al.'s (2009) most likely because of the absence of wind and wave disturbances. In reservoirs, these contribute heavily to degradation of structure and vegetation on shorelines (Miranda 2017). Additionally, the Cereal Barley used in Ratcliff et al. (2009) has a lower acid detergent fiber (measure of cellulose and lignin) concentration than the Triticale used in this study (Harper 2008), meaning that Triticale could be less vulnerable to degradation that Cereal Barley.

Complexity

Characteristics of the complexity of each experimental plant in this study could be used to predict how different life stages of fish would benefit. Considering the two plants that persisted past the required persistence interval (i.e. Marshall Ryegrass and Triticale), Experiment 1 Triticale maintained the highest percentage of its original stem quantity throughout the experiment. Juvenile structure-oriented fish have been shown to select for habitats with higher densities of stems when evading predators (Gotceitas and Colgan 1987, 1990). Thus, plantings of Triticale may provide long lasting structure with high complexity that may be favorable to juvenile fish. Whereas plantings of Marshall Ryegrass will provide a similar percentage of its original height for an equal amount of time as Triticale, however it may lose stems at a greater rate. As the density of stems decreases the size of interstitial spaces among stems will increase allowing larger adult fish to utilize habitat and improve prey capture success (Lynch and Johnson 1989; Lillie and Budd 1992; Dibble and Harrel 1995). Therefore, Marshall Ryegrass could be planted for enhanced habitat with open spaces varying in size and Triticale for enhanced habitat that is dense and complex.

Conclusions

The results of this study suggest use of crops for fish habitat enhancement is feasible. Marshall Ryegrass performed the best for potential adult-fish habitat enhancement and

Triticale for potential nursery habitat enhancement, but triticale will fail if temporarily submerged too early. For agricultural plants to enhance juvenile fish habitat, mudflats need to be sown during the planting season and flooded during the spring following the full life cycle of annual plants. An early flooding event could cause crop failure or rapid degradation of plantings. Conversely, a prolonged drought during the following spring and summer would result in wasted time and resources since the surge of natural vegetation on exposed mudflats would provide more vegetative biomass for fish than the agricultural plantings. Because of this, it is important to plant in a reservoir with predictable drawdown and flooding cycles.

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Temporal Shifts in use of Supplemental Cover by Young-of-Year Fish in Reservoir Mudflats

Reservoir aging poses a major obstacle for achieving fisheries management objectives like maintaining desirable recreational fisheries. Degradation of shorelines and nearshore areas through erosion, sedimentation, loss of submerged structure, and substrate homogenization all decrease structural complexity and are a common concern among reservoir managers (Allen and Aggus 1983; Miranda and Krogman 2015; Pegg et al. 2015). Decreased structural complexity may negatively impact fish diversity, simplify fish communities, alter species composition, and reduce recruitment of key fish species (Valley et al. 2004; Smokorowski and Pratt 2007).

Supplemental cover, in the form of natural or artificial structures added to a water body, alters local fish distributions and community interactions. Habitat complexity is a major driver of fish distribution (Gelwick and Matthews 1990; Bryan and Scarnecchia 1992; Irwin et al. 1997; Jennings et al. 1999; Hatzenbeler et al. 2000; Trial et al. 2001), predator–prey interactions (Hall and Werner 1977; Crowder and Cooper 1982; Savino and Stein 1982; Johnson et al. 1988), and survival of young-of-year (YOY) fish (Aggus and Elliott 1975; Miranda et al. 1984; Bryan and Scarnecchia 1992). Additionally, supplemental cover increases angler catch rates which is often a management objective (Wickham et al. 1973; Wilbur 1978; Mitzner 1981; Boxrucker 1983; Johnson and Lynch 1992; McKinney et al. 1993; Bolding et al. 2004).

Reservoir fisheries managers commonly use supplemental cover as a tool to mitigate the negative effects of reservoir aging. In the United States, 42 of 51 (82%) state fisheries management agencies reported using supplemental cover as a management tool in reservoirs (Tugend et al. 2002). The primary management objectives of supplemental cover use include: increasing angler catch rates, providing fish recruitment/nursery habitat, providing adult habitat/protection, and providing fish spawning habitat (Tugend et al. 2002). The use of supplemental cover with the goal of improving recruitment in reservoir fish populations is widespread, but satisfaction with the effectiveness of this tool is variable (Tugend et al. 2002). Sass et al. (2006) reported that recruitment in YOY Yellow Perch (*Perca flavescens*) dropped tenfold in areas with coarse woody habitat intentionally removed as compared to unaltered areas.

The use of supplemental cover as a management strategy to increase recruitment is poorly understood. Research investigating the potential for supplemental cover to improve fish recruitment and abundance is limited (Tugend et al. 2002). Supplemental cover has been connected to recruitment increases through the ability to provide cover for spawning adults (Vogele and Rainwater 1975; Hoff 1991; Hunt et al. 2002). Investigations of the temporal changes in supplemental cover use by fish communities are also limited. Most research focuses on the changes in supplemental cover use by black bass (*Micropterus spp.*) over time (Strange et al. 1982; Ratcliff et al. 2009). For example, Miranda and Hubbard (1994) reported that added cover increased winter survival of age-0 Largemouth Bass (*Micropterus salmoides*). The impacts of supplemental cover on fish communities over an extended temporal scale has focused on a limited number of species over a narrow temporal range. Strange et al. (1982) and Ratcliff et al. (2009) both investigated the use of supplemental cover by YOY Black Bass over an extended temporal range. The impacts of supplemental cover on fish recruitment in marine fisheries is also poorly understood despite more thorough and frequent investigations than in freshwater systems (Pickering and Whitemarsh 1997). Variability in recruitment of fishes makes it difficult to connect changes in fish abundance to a specific management action (Tugend et al. 2002). Thus, management actions are rarely evaluated for their effectiveness in meeting management objectives.

The inability to draw connections between supplemental cover and fish recruitment has called in to question the effectiveness of supplemental cover as a management tool to improve fish recruitment. The objectives of this study were to: (1) evaluate differences in abundance and size of YOY fish in areas with and without supplemental cover, (2) evaluate temporal differences in abundance of YOY fish species occupying supplemental cover, and (3) evaluate the influence of brush pile size and depth placement on local YOY fish biomass and abundance.

Methods

Experimental Design

In February 2017, the USACE deployed 196 supplemental brush pile structures in Long Branch Creek embayment on Enid Reservoir to provide supplemental fish habitat (Figure 1). Brush piles consisted of Red Cedar (*Juniperus virginiana*) and Bald Cypress (*Taxodium distichum*) anchored with cement blocks and aluminum wire. We recorded GPS coordinates and measured length, width, and height dimensions in meters with a tape measure for all brush pile structures before they were flooded by seasonal water increases. Brush pile volume was calculated as the product of brush pile length, width, and height.

Sampling Design

We randomly selected and sampled 60 brush pile sites and 60 control sites, hereafter referred to as treatments. Control sites were those without brush, spaced at least 20 m away from any structures (e.g., shore and brush piles), and within the Long Branch Creek embayment. Fish were sampled from May to September 2017. Sampling events occurred over two consecutive days and were spaced out approximately every 3 weeks. Six sampling events were completed during the study period, with 20 samples per event, 10 in brush piles sites and 10 in control sites.

We surrounded sampling sites with a block net 30 m long (Figure 2) and 2 m deep with 2 mm mesh following procedures similar to those described by Bettoli and Maceina (1996). Rotenone was then applied to the surrounded area to achieve a concentration of 1 ppm to capture fish. A depth measurement (m) was also taken for each site. The net area was monitored until all fish were collected, usually about 25 minutes. Individual fish were identified to species and total length (mm TL) recorded. Young-of-year fish were placed on ice to transport to a laboratory where batch weights by species were recorded.

Figure 1. Recording characteristics of fish attractors before inundation.

Data Analysis

To compare fish assemblages between treatments and over time, analyses were limited to YOY of species present in at least one-third of all samples to avoid the sensitivity of multivariate analysis to uncommon species. These species included: Common Carp (*Cyprinus carpio*), Gizzard Shad (*Dorosoma cepedianum*), Bluegill (*Lepomis macrochirus*), Largemouth Bass (*Micropterus salmoides*),

Figure 2. Sampling inundated fish attractors in Enid Lake.

White Crappie (*Pomoxis annularis*), and Black Crappie (*Pomoxis nigromaculatus*). Length frequency plots were used to identify the maximum total length for the newest year class for each species of interest.

Comparing YOY fish assemblages between supplemental cover and control sites.- We applied a permutational analysis of variance (PERMANOVA; Oksanen et al. 2017). The dependent variables in the PERMANOVA were abundance of YOY fish of species of interest, and the independent class variable was treatment. Species counts were $\log_e$+1 transformed to reduce excessive dispersion. Differences were deemed significant when $P \leq 0.05$. Non-parametric PERMANOVA was used to avoid the potential violation of the assumptions of normal distributions of fish among sites and homogeneity of variances (Anderson 2001). If differences between treatments were detected, boxplots were used to visualize variations between treatment types for each of the six species of interest. PERMANOVA were performed using the Adonis function of the vegan package in program R (R Development Core Team, 2010).

We used the lmer function of the lme4 package in program R to create a multiple regression model to evaluate size of YOY fish (Bates et al. 2015). The model predicted the total length (TL) of YOY fish using time, site type (brush pile or control), the interaction between time and fish species, and the interaction between time and treatment. A random effect of time on individual sampling sites was used to account for the repeated observations for each site. Analysis of Variance (ANOVA) was then used to identify possible differences in YOY TL between treatments and over time, and possible interactions between time and species, and between time and treatment. Differences were deemed significant when $P \leq 0.05$.

Evaluating temporal differences in YOY fish assemblages occupying supplemental cover.- We conducted a PERMANOVA using data from the 60 brush pile samples to contrast YOY fish assemblages over time (Oksanen et al. 2017). Species counts were $\log_e$+1 transformed to handle skewed data. Differences were deemed significant when $P \leq 0.05$. If temporal differences were identified by the PERMANOVA, boxplots were used to visualize variations between sampling events for each of the six species of interest. PERMANOVA were performed using the Adonis function of the vegan package in program R (R Development Core Team, 2010).

Evaluating the influence of brush pile size and depth on YOY fish assemblages.- We conducted two separate analyses using YOY of the 6 species of interest occupying the 60 brush pile sites. First, multiple linear regression was used to predict the biomass (g) of YOY fish based on brush pile volume (m^3) and brush pile depth (m). Week was included as a class variable to account for the effect of time. Next, multiple linear regression was used to predict the abundance (number) of YOY fish based on brush pile volume (m^3) and brush pile depth (m). Week was included as a class variable to remove the effect of time. The $\log_e$+1 of the dependent variable was used to linearize data. Both regression models were fit using program R. A total of 13 models consisting of all combinations (main effects and interactions) of the two environmental factors of interest and a temporal factor were evaluated using Akaike

Information Criterion (AIC), corrected for small-sample size (AICc), and Akaike weights (w_i) (Akaike 1987; Burnham and Anderson, 2002). I used the combination of these three factors to evaluate the parsimony and fit of each model and select the most adequate of the 13 models. Model coefficients (beta values) from the most adequate model were used to predict biomass response for a simulated data set to predict the effect of brush pile depth and volume. The dataset was created using systematic combinations of observed ranges of explanatory variables. Model predictions were used to create line graphs to evaluate the influence of brush pile features on YOY fish.

Results

We collected 12,788 fish representing 21 species at the 120 sampling sites. YOY fish accounted for 11,169 (87%) of all fish collected. Depths of sampling sites varied from 0.5 to 1.4 m. Volumes of brush piles sampled varied from 0.8 to 157.4 m^3.

YOY fish communities in supplemental cover and control sites.- Young-of-year Fish assemblages differed significantly between brush pile and control sites (PERMANOVA,

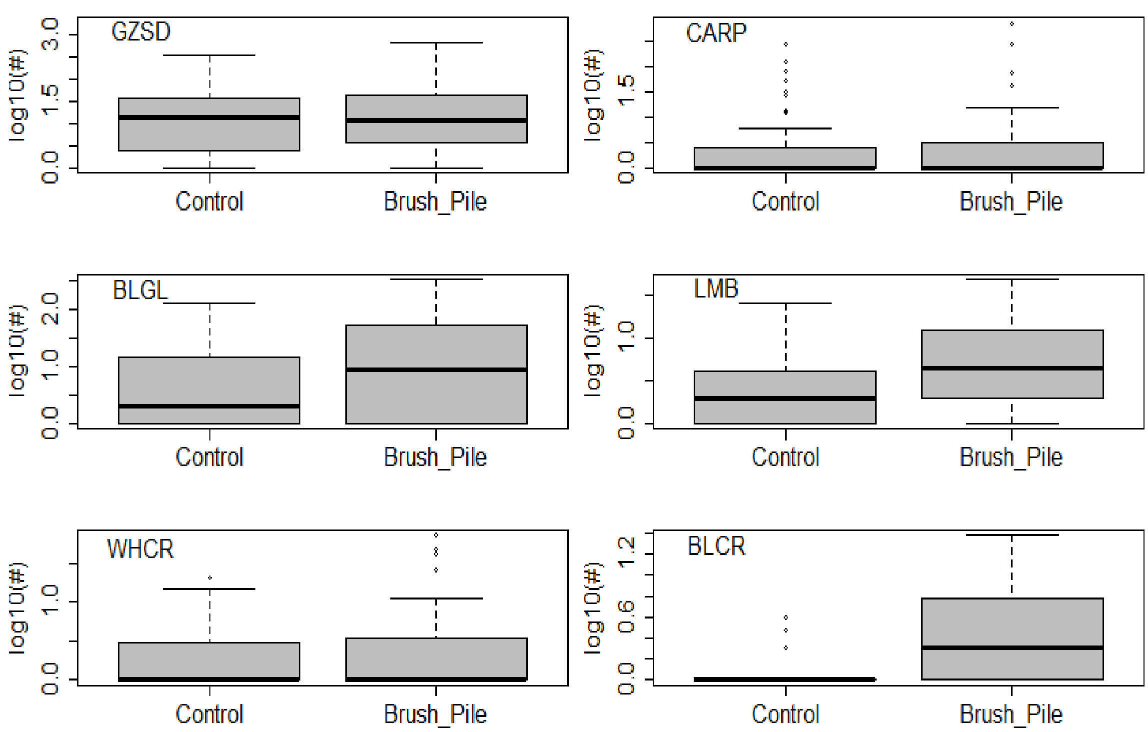

Figure 3. Boxplots showing variations in young-of-year fish abundances between treatment types for 6 species of interest. Differences in Log_{10} abundances of 6 YOY species between brush pile and control sampling sites collected in 2017 at Long Brand Creek, Enid Reservoir, Mississippi. (GZSD=Gizzard Shad, CARP=Common Carp, BLGL=Bluegill, LMB=Largemouth Bass, WHCR=White Crappie, BLCR=Black Crappie).

P=0.02). Three species, Bluegill, Largemouth Bass, and Black Crappie showed higher abundance on average in brush pile sites as compared to control sites (Figure 3). Gizzard Shad, Common Carp, and White Crappie showed little difference in abundance between treatments (Figure 3).

Total length (TL) of YOY fish varied among treatment types (ANOVA, P<0.01), over time (ANOVA, P=0.01), interacted with time and species (ANOVA, P<0.01), and did not interact with time and treatment type (ANOVA, P=0.06). In brush pile sites YOY fish had a median TL of 42 mm and varied from 16 mm to 120 mm. In control sites YOY fish had a median TL of 39 mm and varied from 15 mm to 118 mm. Multiple regression revealed larger fish in brush piles sites compared to control sites during a majority of the sampling season (Figure 4)., Fish of all 6 species were predicted to be larger in brush pile sites than those in

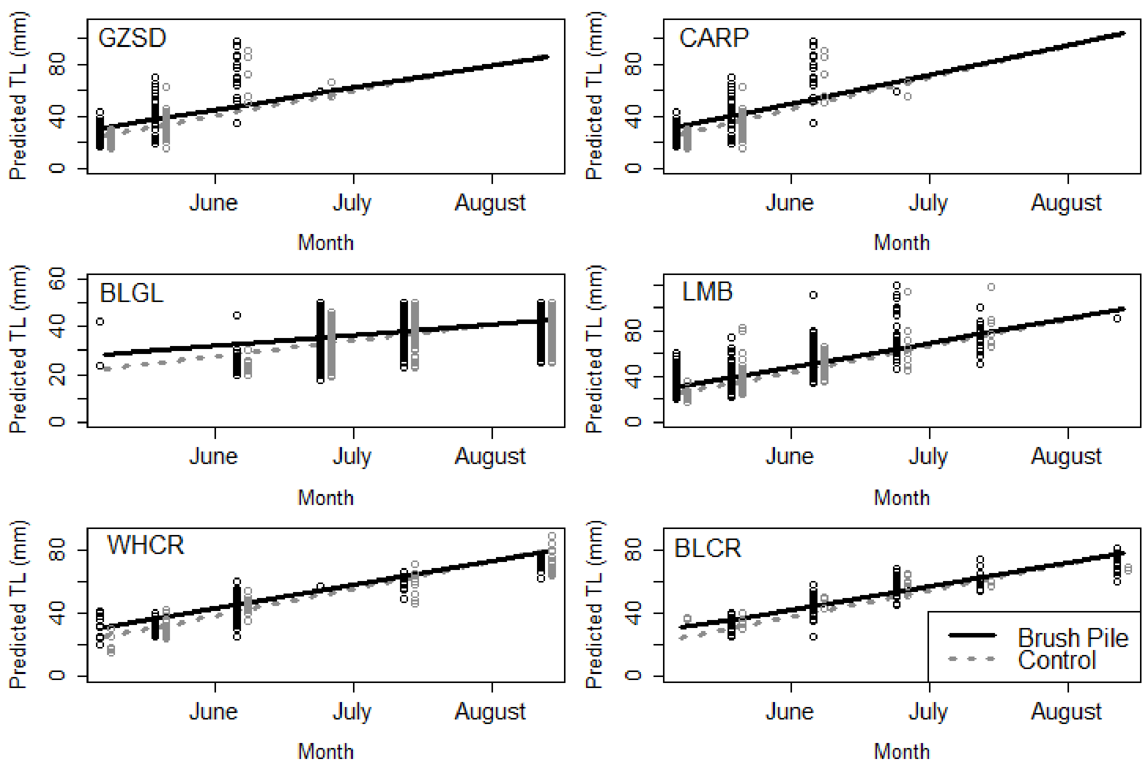

Figure 4. Differences in model predicted young-of-year (YOY) total length (TL) values between treatment types for 6 species of interest. Predicted TL of YOY fish plotted against time of year (month) generated by linear model with random effects for both brush pile (black) and control (gray) sites. Fish collected during sampling in 2017 at Long Brand Creek, Enid Reservoir, Mississippi are denoted with points (GZSD=Gizzard Shad, CARP=Common Carp, BLGL=Bluegill, LMB=Largemouth Bass, WHCR=White Crappie, BLCR=Black Crappie).

control sites in early portions of the sampling season. Later in the sampling season, we observed an overlap on predicted TL values for all YOY fish species between treatment types.

Temporal differences in YOY fish assemblages occupying supplemental cover.- Fish assemblage structure differed significantly over the duration of the sampling season (PERMANOVA, $P<0.01$). Gizzard Shad YOY abundance at brush pile sites remained relatively stable throughout the sampling season, peaking in June (Figure 5). All other species showed abundances that increased, peaked, and later decreased. The timing of peaks in abundances differed among species. Common Carp and Largemouth Bass peaked earlier in the sampling season while bluegill abundances peaked later (Figure 5).

Influences of brush pile size and depth on YOY fish assemblages.- Model selection revealed the best approximating model for predicting YOY biomass included an effect of brush pile

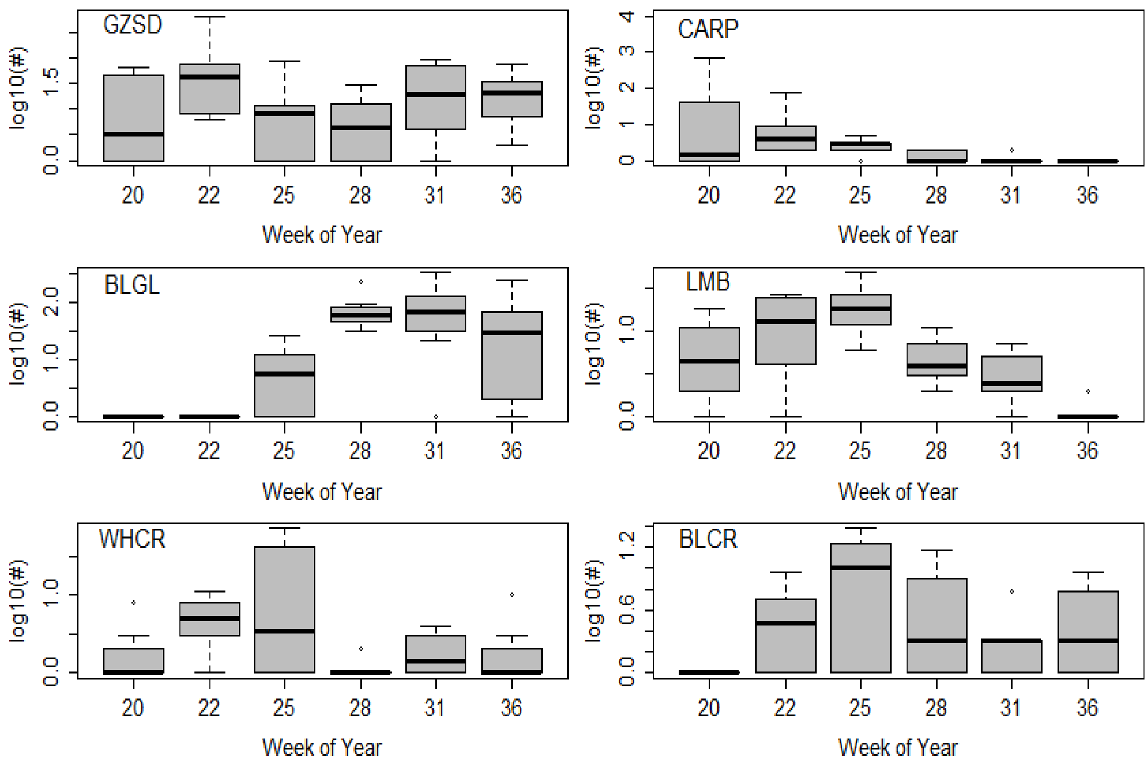

Figure 5. Boxplots showing variations in young-of-year fish abundances in supplemental cover between sampling events for 6 species of interest. Differences in Log_{10} abundances of 6 YOY species during different sampling events collected in 2017 at Long Brand Creek, Enid Reservoir, Mississippi. (GZSD=Gizzard Shad, CARP=Common Carp, BLGL=Bluegill, LMB=Largemouth Bass, WHCR=White Crappie, BLCR=Black Crappie).

Table 1. Model selection criteria for multiple regression model predicting young-of-year biomass of Common Carp, Gizzard Shad, Bluegill, Largemouth Bass, White Crappie, and Black Crappie. Table includes model factors, degrees of freedom (df), Akaike Information Criterion (AIC), small-sample corrected AIC (AICc), change in AIC from most adequate model (Δ AIC), and model weight (w_i).

Model	df	AIC	AICc	Δ AIC	w_i
Volume + Time	57	167.69	168.42	0.00	0.41
Volume * Depth + Time	55	168.77	170.36	1.08	0.24
Volume * Time	56	169.43	170.54	1.74	0.17
Depth * Time + Volume	55	170.97	172.55	3.37	0.08
Volume * Time + Depth	55	171.42	173.00	3.73	0.06
Depth * Time * Volume	52	173.47	177.07	5.78	0.02
Time	58	174.70	175.13	7.01	0.01
Depth + Time	57	176.67	177.39	8.97	<0.01
Depth * Time	56	178.48	179.59	10.78	<0.01
Volume	58	200.05	200.47	32.35	<0.01
Volume + Depth	57	200.17	200.90	32.48	<0.01
Volume * Depth	56	200.68	201.79	32.99	<0.01
Depth	58	202.58	203.00	34.88	<0.01

volume and time as $\log_e(\text{Biomass}+1)=3.05+0.01*\text{Volume}+0.15*\text{Time}$. Two models had ΔAIC scores of less than 2, but both were more complex versions of the best approximating model (Table 1). All factors in the model have significance in the regression as well as positive coefficient estimates (Table 2). Model fit was moderate with an R^2 value of 0.47. Predictions generated from the best approximating model indicate greater biomass accumulates at higher volume brush piles (Figure 6). Additionally, the difference in biomass between large and small brush piles was greater in samples from later in the sampling season (Figure 6).

Table 2. Summary of multiple regression model for young-of-year biomass of Common Carp, Gizzard Shad, Bluegill, Largemouth Bass, White Crappie, and Black Crappie including relevant inputs, beta estimates (estimate), standard error values (std. error), significance values (p), and 95% Confidence Interval (95% CI).

Input	Estimate	Std. error	p	95% CI
Intercept	3.05	0.25	<0.01	2.55 – 3.55
Volume	0.01	<0.01	<0.01	0.00 – 0.02
Time	0.15	0.02	<0.01	0.10 – 0.19

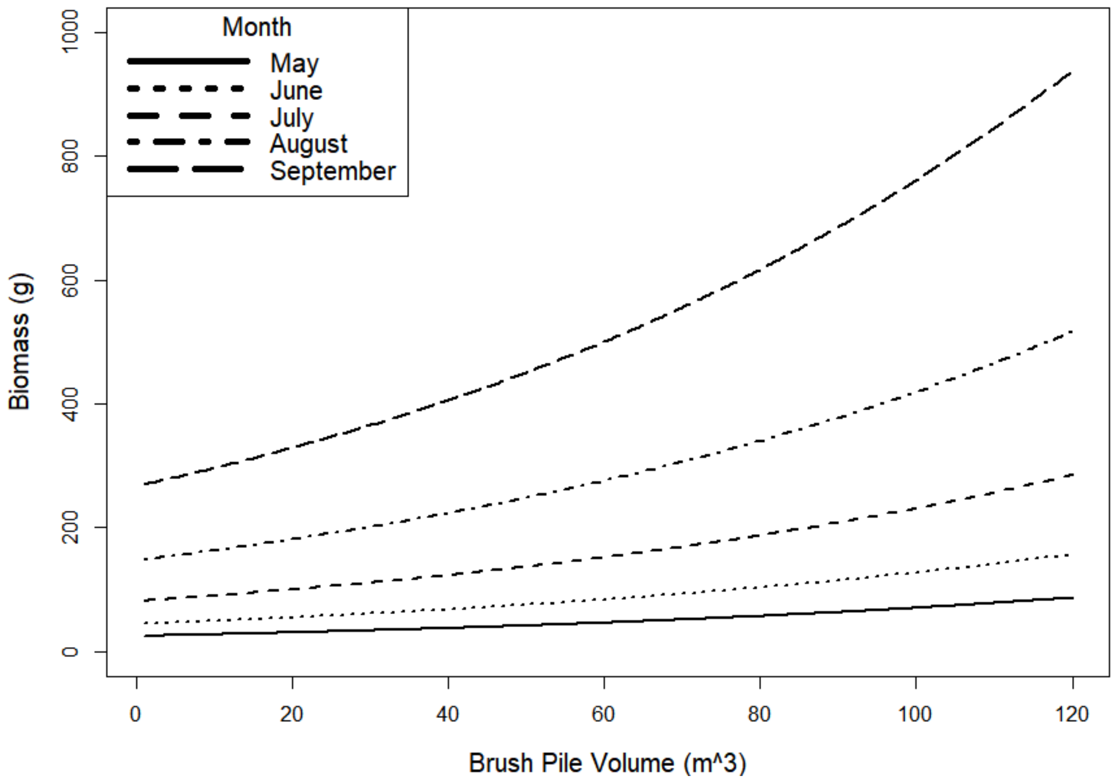

Figure 6. Predicted YOY biomass based on brush pile volume for varying months of the year. YOY biomass plotted with respect to brush pile volume with 5 series representing different months of the year. Values predicted using multiple regression model and simulated data sets. Model predictions made based on data collected in 2017 at Long Brand Creek, Enid Reservoir, Mississippi.

Model selection revealed the best approximating model for predicting YOY abundance used brush pile volume, brush pile depth and the interaction between volume and depth as $\log_e$(Abundance+1)=2.05+0.04*Volume+1.88*Depth+-0.03*Volume*Depth. Two models had Δ AIC scores of less than 2, but one was a more complex version of the best approximating model and the other had almost half the model weight of the top model (Table 1). All factors in the model had significance in the regression except for depth and all factors had positive coefficient estimates except for the interaction between depth and volume (Table 3). Model fit was low with an R^2 value of 0.26. Predictions generated from the best approximating model indicated that the greatest abundances of YOY fish occur at higher volume brush piles (>80 m^3) at shallower sites (<0.75 m) (Figure 7). Conversely, higher abundances occur at brush piles of smaller volume (< 50 m3) in deeper areas (>0.75 m) (Figure 7).

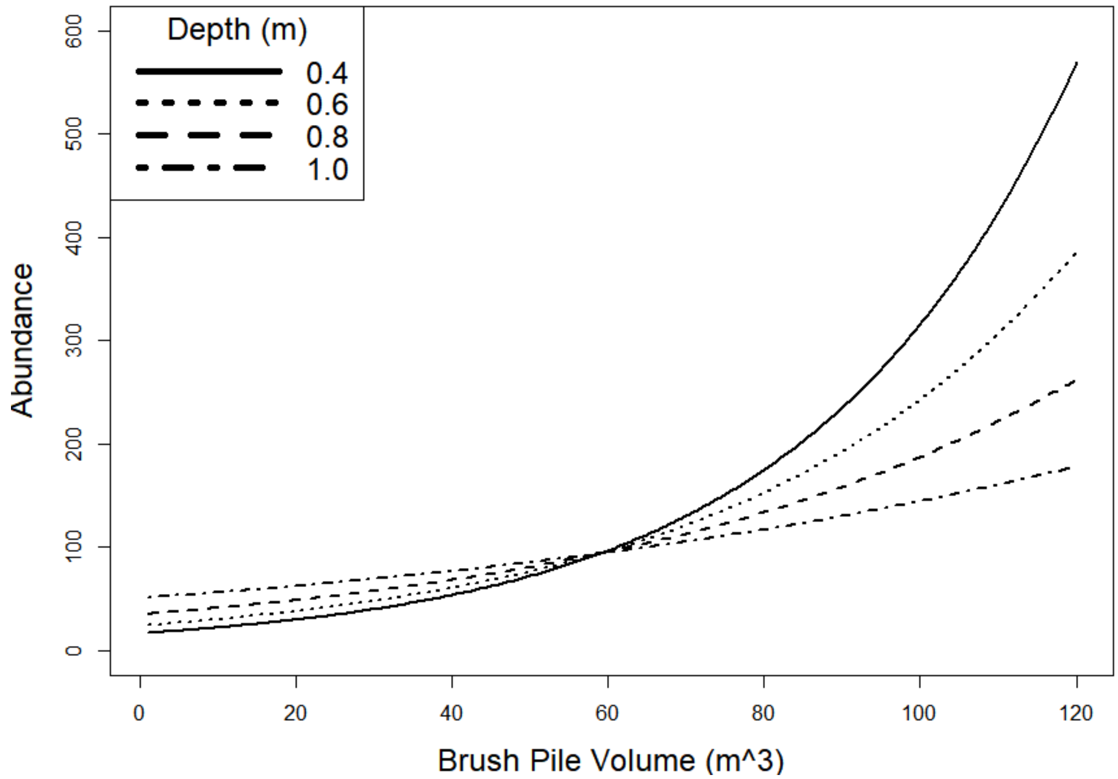

Figure 7. Predicted YOY abundance based on brush pile volume for varying depths of the year. YOY abundance plotted with respect to brush pile volume with 4 series representing different water depths. Values predicted using multiple regression model and simulated data sets. Model predictions made based on data collected in 2017 at Long Brand Creek, Enid Reservoir, Mississippi.

Discussion

Species specific YOY abundance and biomass differed with supplemental cover over time. Centrarchids exhibited higher abundances in brush piles in agreement with observations made by Bolding et al. (2004). Additionally, the presence of larger YOY fish at brush pile sites early in the season indicates either higher initial growth rates in brush piles or competition for limited cover being won by larger individuals. Variations in use of littoral brush piles by YOY fish over time track the natural temporal distribution of spawning (Lane et al. 1996), with species which spawn earlier in the growing season recruiting to brush earlier than those that spawn later in the growing season. Young-of-year biomass was highest in larger brush piles later in the year similar to the observations of greater biomass in larger marine fish attractors (Bohnsack et al. 1994).

The influence of water depth on YOY abundance varied with respect to brush pile size. YOY abundance was greater at larger brush piles in shallower areas. Evaluations of fish distributions based on depth in freshwater systems have been limited (Miranda 2011; Miranda and Killgore 2014), this is especially true of YOY fish. However, similar trends have been observed for YOY biomass in marine fisheries with respect to reef structures (Bohnsack et al. 1994; Gratwicke and Speight 2005). The observed preference for shallower depths in YOY fish was not expected given high summer water temperatures and increased vulnerability to avian predators. The observed increases in YOY abundance associated for larger brush piles at shallower depths may result from predators avoiding excessively shallow water with high summer temperatures. Additionally, large shallow brush piles receive more sunlight and provide a greater area to promote epiphytic growth indicating foraging opportunities may be higher at these sites. Nevertheless, additional research is needed to accept or refute these conjectures.

Management Implications

Supplemental cover has been shown to improve fisheries (Tugend et al. 2002), but questions remain as to the magnitude of effect and mechanisms associated with additions of cover. At peak abundance (i.e., June) density of YOY Largemouth Bass in Enid Reservoir averaged 2,873 fish/ha in brush and 620 fish/ha in sites without cover. Given these and hypothetical brush pile coverages of 1, 5, 10, and 20% area of a reservoir embayment then estimated density of YOY Largemouth Bass is 642, 732, 845, and 1,070 fish/ha, respectively. These estimates assume a linear relationship between fish density and cover and may entail that additional numbers reflect increased production rather than simply attraction. Using similar sampling methods, Hoyer and Canfield (1996) estimated a density of 6,000 Largemouth Bass/ha in a small Florida lake with 7% aquatic vegetation coverage. In West Point Reservoir, Alabama-Georgia, Miranda et al. (1984) estimated peak abundance (June) averaged 600 Largemouth Bass/ha in a year when the water level was held below summer pool, and 1200-3800 fish/ha in years when the water levels inundated terrestrial vegetation above summer pool. Thus, increasing the percentage of brush within the reservoir may in turn increase the density of YOY Largemouth Bass closer to levels seen in naturally-vegetated lakes, or in flooded wooded areas of the riparian zone.

Fisheries managers implementing supplemental cover as a management tool have been provided little guidance for selecting brush pile volume and placement locations. YOY fish abundance can be maximized by placing large brush piles (> 80 m^3) in shallow water (< 0.75 m). If smaller brush piles (< 50 m^3) are used they should be placed in deeper water (1-1.5 m). The relationship between size of structure and interstitial space has been identified as a good predictor of fish use (Savino and Stein 1982; Johnson et al. 1988; Daugherty et al. 2014). Results from this study provide evidence that brush piles provide benefits to YOY fish, potentially resulting from a greater variety of sizes in interstitial spaces provided in larger brush piles. Investigations have been made into the connections between depth and fish use of structures, but all have focused on adult fish (Prince and Maughan 1979a; 1979b; Lynch and Johnson 1988a; 1988b).

Our observed association between cover and YOY fish supports the use of supplemental cover as a tool to potentially improve YOY fish recruitment. Furthermore, if temporal variations in use of supplemental cover indicates respective recruitment by different species, this study highlight the importance of providing cover for YOY fish in littoral areas throughout the duration of the growing season. Apparent increased growth during the early portion of the sampling season may indicate increased production resulting from supplemental cover. Future research should investigate the connections between changes of densities of supplemental cover and densities of YOY fish to quantify direct benefits to total production resulting from increases in cover. Additional understanding of the connection between cover and direct recruitment to fisheries could facilitate more conclusive evidence to reveal if supplemental habitat simply concentrates existing individuals or increases fish production, a question that has long troubled fisheries scientists (Pickering and Whitemarsh 1997).

Fisheries managers will continue to be challenged by reservoir aging and associated negative effects on fish communities. Understanding the value of supplemental cover, allows managers to effectively implement this management action and increases the likelihood of favorable results. Thus, the need for continued research into the connections between supplemental cover use and YOY fish recruitment still exists. Future research may focus on other aspects of supplemental cover, such as material and design of structures, which have been evaluated in their connection to meeting management objectives like increased angler catch rates and adult fish use but recruitment habitat (Tugend et al. 2002). Investigations into the impacts of depth and area on YOY recruitment could likely benefit from a wider range of sampled depths as well as finer scale measurements of brush pile structures which account for factors such as interstitial space.

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