FISH HABITAT RESTORATION OF AN OXBOW LAKE IN THE MISSISSIPPI DELTA

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ABSTRACT

Lake Whittington, historically contiguous with the Mississippi River, now experiences annual de-watering. A weir proposed for the inlet/outlet channel would permit water exchange during high river stages, and pool water when river stages are low. We developed regression models from empirical data and, using Habitat Evaluation Procedure (HEP) incrementally quantified fishery benefits associated with alternative weir heights.

Fish-habitat data were collected in summer 1995 from 3 oxbow lakes in the Mississippi River: Lake Bolivar (permanently isolated from the Mississippi River); Lake Whittington; Lake Beulah (seasonally connected, with a weir pooling water during low river stages). Depth and water quality were measured at 9 stations in each lake. Fishes were sampled using overnight sets of floating Plexiglas traps "baited" with chemical light sticks. Young-of-year sunfishes (*Lepomis* spp.) and inland silverside (*Menidia beryllina*) were numerically dominant. Fish abundances were used as dependent (response) variables, physical habitat data as independent variables in regression models. Both taxa were negatively correlated with mean cross-sectional lake depth ($p < 0.01$), sunfish predominating at depths < 2 m, silversides at 6 m. Habitat Suitability

Index (HSI) curves, values of which range from 0.00 (no habitat value) to 1.00 (optimum habitat), were constructed from standardized fish frequency distributions and regression. Habitat under existing conditions and for 5 weir heights was quantified as Habitat Units (HU's) by multiplying surface area of specific lake depths with corresponding HSI values. HU's for both taxa increased substantially at the lowest weir height. Sunfish HU's asymptoted at an intermediate weir height, silverside HU's increased linearly over the full range of weir heights. Model verification is not possible until a weir is constructed, but abundance of littoral fishes in the three lakes strongly supports the results of HEP simulations.

INTRODUCTION

Lake Whittington is an oxbow lake of the Mississippi River, commercially and recreationally fished for more than 50 years, but now experiencing declining fisheries and progressive seasonal dewatering. Standing crops of black crappie (*Pomoxis nigromaculatus*) have decreased and common carp (*Cyprinus carpio*) increased; reproduction of largemouth bass and densities of intermediate sized sunfishes are low (Lucas, 1992). Dewatering may reduce availability of spawning area in littoral zones and concentrate fishes thereby increasing predation.

During high and intermediate stages on the Mississippi River, the surface elevation of Lake Whittington is controlled by the Mississippi River via an inlet/outlet channel. Bottom of the inlet/outlet channel and natural obstructions in the lake control the surface elevation of the lake during low stages of the Mississippi River. During low stages, the lake is dewatered, isolated from the river, and dries partially to form three separate pools consisting of approximately 405 hectares. Bankfull surface area of the lake is 1215 hectares. The lake typically dewaters during late summer and may remain in this condition through late autumn. Users of the lake have noted that the lake elevation declines to lower elevations with greater frequency, duration, and magnitude than previously. Consequently, a water control structure in the inlet/outlet channel was recommended to maintain a minimum pool during late summer and autumn. Engineering studies indicate that a compacted earth and stone weir is structurally adequate for the weir elevations investigated. Construction would be performed during late summer when the Mississippi River is at its lowest stages.

A weir would minimize negative effects of dewatering on the fishery. To determine weir height providing greatest fish habitat benefits, we evaluated 5 alternative weir elevations. We quantified spawning and foraging habitat by modeling abundances of young-of-year sunfishes and inland silverside respectively. Sunfishes, as a group and as individual species, spawn from mid-April through September (Robison and Buchanan, 1988; Turner *et al.*, 1994). They are abundant in oxbow lakes and intensively exploited by anglers. Inland silversides also exhibit a prolonged reproductive season, possibly from March through September (Hildebrand, 1922; Hubbs, 1982; Middaugh and Hemmer, 1992). They were historically abundant in Mississippi delta oxbows (Cook, 1959), but recent surveys suggest low numbers (Robison and Buchanan, 1988; Baker et al., 1991), possibly due to very high water temperatures (> 37 °C) recorded during low water (Lowery *et al.*, 1987; Lucas 1992). Temperatures over 30 °C are believed critical in cessation of spawning, and in post-spawning mortality (Hubbs and Bailey, 1977; Hubbs and Dean, 1979). Inland silversides are an important link between invertebrates and piscivorous fishes; they eat zooplankton and surface insects (McComas and Drenner, 1982) and are consumed in large numbers by temperate and black basses (Mense, 1967; Echelle and Mense, 1968; Matthews et al., 1992).

STUDY SITES

We surveyed Lake Whittington and two nearby oxbow lakes of the Mississippi delta, north of Greenville, MS (Fig. 1). Lake Bolivar occurs near river km 904 and is permanently isolated from the Mississippi River by a mainline levee constructed in the 1930's. It is surrounded by agricultural fields. There is a thin line of trees around the perimeter, and

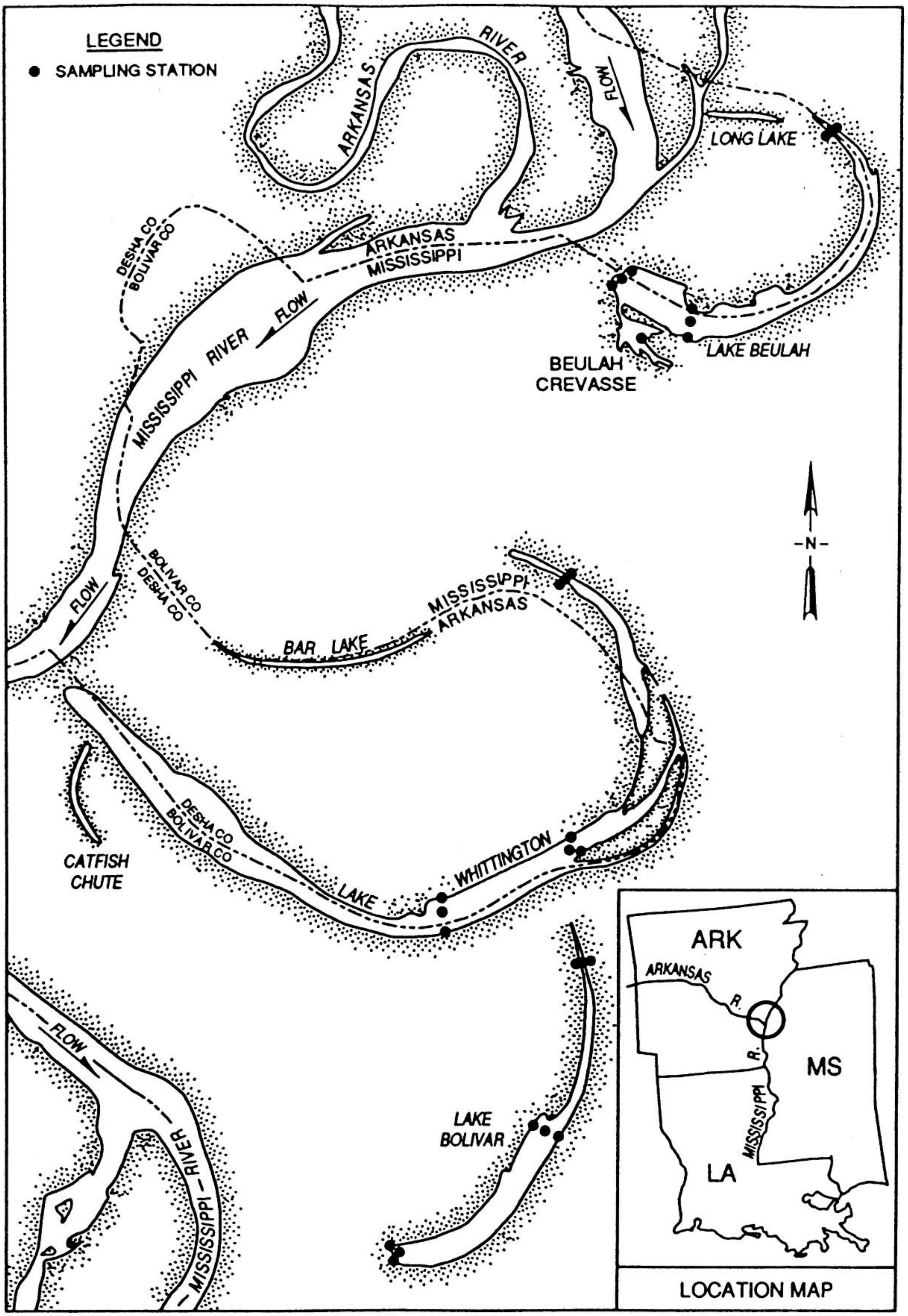

Fig. 1. Oxbow lakes and stations sampled by light-trap

hardwood forests at the upper end of the lake. Lake Whittington occurs near river km 926, and was formed in 1937 by the U.S. Army Corps of Engineers after completion of Caulk Island Cutoff. Several residences and fishing camps are located on the edge of the lake. Lake Beulah occurs east of the Rosedale Bend near river km 939. It was created in 1863 as a result of the Napoleon Bend cutoff, and a weir constructed in 1955 (Lucas, 1992). Lakes Whittington and Beulah occur on the Mississippi River floodplain, riverward of mainline levees, and are largely surrounded by hardwood forests. They are flooded seasonally (Jan-Apr), and dewatered in late summer-early autumn, especially in Lake Whittington, in which water is not pooled by a weir.

MATERIALS AND METHODS

Field sampling - Floating Plexiglas light traps were used to collect surface fishes (Killgore 1994). Light traps (n=3) were placed at nine stations: upper, middle, and lower lake at outer shoreline, mid-channel, and inner shorelines (Fig. 1). Lake Bolivar was sampled 13-14 Jun 95, Lake Whittington 14-15 Jun 95, and Lake Beulah, 15-16 Jun 95. At Lake Beulah, a fourth station, Beulah Crevasse (also known as Merigold Lake), was sampled. Each trap was "baited" with a yellow Cyalume™ chemical light stick (minimum illumination of 12 hours), deployed early evening (1730-2000), and recovered the following morning. All fishes were preserved in 5% formalin. In the laboratory, fishes from each sample were sorted; juveniles and adults were transferred to 50% isopropanol, larvae were stored in 5% formalin. Specimens were deposited in collections of Northeast Louisiana University Museum of Zoology and the Waterways Experiment Station Environmental Laboratory.

Depth and water quality were measured at each light trap. A cross-sectional transect was designated and water depth measured at 10 approximately equi-distant points with a surveyor's stadia rod (< 5 m) or with a portable SONAR depth gauge (> 5 m). Turbidity of surface water was measured using a Hach 2100P turbidimeter. Water temperature, conductivity, dissolved oxygen, and pH were measured using a Hydrolab submersible water quality probe at lake surface and near lake bottom.

Habitat Evaluation Procedure - Benefits were calculated using the Habitat Evaluation Procedure (HEP) which expresses habitat quantity as habitat area weighted by habitat quality (USFWS, 1980), i.e.,

Habitat Units = Habitat Area X Habitat Suitability Index

Empirical (curvelinear) relationships between fish abundance and physical habitat may be used to objectively identify significant habitat variables and quantify habitat value. This approach necessitates two assumptions:

1) Fish abundance is a positive, direct expression of habitat quality.
2) Relevant habitat variables, and ranges for those variables, were included in analysis.

To identify relevant habitat variables, we used Pearson product moment correlation coefficients and multiple regression analysis, MAXR (SAS, 1985). This provided quantitative models of relationship between one or more independent (habitat) variables and a single dependent (fish abundance) variable. Regression models were expressed as

$$\textbf{Fish abundance} = \textbf{b} + \textbf{m}_1\textbf{Habitat Correlate}_1 + \textbf{m}_2\textbf{Habitat Correlate}_2\textbf{...}$$

in which habitat correlates are parameters significantly correlated with fish abundance, b (y-intercept) and m (slope) are constants. Model allows abundance of fish (number/light-trap) to be predicted for specific values of habitat variables. Regression equations were used as formula to calculate indices of habitat quality or Habitat Suitability Indices (HSI's). This was done by dividing by the maximum predicted value for the dependent variable: i.e., number of fish calculated for modal value(s) of primary habitat correlate(s).

$$\text{HSI} = \frac{b + m_1 \text{Habitat Correlate}_1}{\text{Maximum fish abundance}}$$

Equation standardizes calculated values of fish abundance to a scale ranging from 0.00 (no habitat value) to 1.00 (maximum habitat value).

Bathymetric data for Lake Whittington were used to calculate surface areas of different intervals of water depth for existing conditions and for alternative weir elevations using planimetry.

RESULTS

Physical habitat - Lake Bolivar was shallow (< 2 m), moderately conductive (103-167 umhos), with a longitudinal turbidity gradient (upper-lower ends of lake, 10-382 NTU's). Lake Whittington was deep (11-18 m), highly conductive (349-363 umhos), and clear (4.9-9.1 NTU's). Lake Beulah was moderately deep (7-11 m), highly conductive (350-381 umhos), and clear (6.2-15.3 NTU's). In all three lakes, water temperatures were warm (24-27 ° C), and pH was neutral to basic (7.2-8.5). Most values of dissolved oxygen ranged from 4-10 mg/l. Hypoxia (< 2.0 mg/l) was observed, however, in Lake Whittington: surface and bottom waters in the upper lake, bottom waters middle and lower lake. In Lakes Beulah and Whittington, ranges were narrow for surface water temperature (< 2.2 ° C), conductivity (< 35 umhos), and pH (< 0.8), so these variables were excluded from fish-habitat correlation analyses.

Fish-habitat relationships - Light-traps (n=83) collected 3208 fish, representing at least 12 species (Table 1). Catch rates ranged from 0 to 299 fish/trap-night. Inland silversides and young-of-year sunfishes respectively constituted 73 and 22 % of all fishes. The third-most abundant species, threadfin shad, constituted only 2.5% of fish. No inland silversides were collected in Lake Bolivar; mean number was

8.0/trap-night in Lake Whittington and 70.8/trap-night in Lake Beulah. Conversely, maximum abundance of sunfishes was observed in Lake Bolivar, 22.6/trap-night; moderately low catches were obtained in Lake Whittington, 1.5/trap-night, and Lake Beulah, 1.0/trap-night.

Habitat correlates were similar for both taxa. Sunfishes and silversides were negatively correlated with mean water depth, range of water depths, and water depth at trap ($r < -0.36$, $p < 0.010$), and positively correlated with turbidity ($r > 0.43$, $p < 0.001$). Silversides were positively correlated with dissolved oxygen ($r = 0.27$, $p = 0.04$), but sunfishes were not ($r = -0.02$, $p = 0.83$). Stepwise multiple regression resulted in the following models for both taxa:

$$\text{Sunfishes} = 14.518 - 1.096(\text{Mean Depth}) + 0.039(\text{Turbidity}),$$
$$r^2 = 0.309,\ p = 0.0001$$

$$\text{Silversides} = 46.401 - 5.768(\text{Mean Depth}) + 5.543(\text{Turbidity}),$$
$$r^2 = 0.243,\ p = 0.0006$$

Modified habitat models - Although statistically significant, above models assume a consistent negative (linear) relationship of fish abundance with depth. Fish abundance, however, was highest at some intermediate depth: 1.3 m for sunfish, 6.3 m for silversides (Fig. 2). Regressions were recalculated so that depth corresponding to modal fish abundance was used as a starting point for two separate regressions: a positive regression from 0 depth to depth of modal abundance, and a negative regression from depth of modal abundance to maximum depth of occurrence. Since turbidity is not expected to change as a result of the project, "second generation" models did not include that variable. Regressions were standardized by dividing by maximum predicted fish abundance:

Table 1. Total numbers of fishes collected in three Mississippi River oxbow lakes using light-traps, 13-15 Jun 1995. Silversides and mosquitofish included larvae, juveniles, and adults. Other taxa were comprised exclusively by larvae and small juveniles.

	Bolivar n = 27	Whittington n = 26	Beulah n = 30
Sunfishes			
Bluegill, *Lepomis macrochirus*	1	3	1
Warmouth, *L. gulosus*	1		
Unidentified sunfishes, *Lepomis* sp.	611	68	31
White crappie, *Pomoxis annularis*	1		
Forage Fishes			
Threadfin shad, *Dorosoma petenense*		38	41
Unidentified clupeids, *Dorosoma* sp.		6	14
Unidentified topminnows, *Fundulus* sp.			1
Brook silverides, *Labidesthes sicculus*		3	10
Inland silversides, *Menidia beryllina*		207	2124
Unidentified silversides, Atherinid sp.		1	
Other Fishes			
Spotted gar, *Lepisosteus oculatus*	1	2	
Common carp, *Cyprinus carpio*		4	
Yellow bullhead, *Ameiurus natalis*	1		
Channel catfish, *Ictalurus punctatus*	1		
Mosquitofish, *Gambusia affinis*	31	2	4
Total fishes	648	334	2226

$$HSI_{Sunfish > 1.3\ m} = \frac{21.699 - 1.693(\text{Mean depth})}{19.6}$$

$$HSI_{Sunfish < 1.3\ m} = \frac{-31.608 + 47.664(\text{Mean depth})}{26.5}$$

$$HSI_{Silversides > 6.3} = \frac{122.724 - 8.094(\text{Mean depth})}{73.4}$$

Because no silversides were collected in Lake Bolivar where depths were less than 1.3 m, we assumed an HSI of 0.00. In the other two lakes, no silversides were collected at mean depths less than 6.3 m but we assumed fish were present at these depths. Consequently, a positive linear relationship for the depth interval of 1.3 to 6.3 m was obtained from Figure 3 using HSI values as the dependent variable in the regression:

$$HSI_{Silversides < 6.3\ m} = -0.250 + 0.203(\text{Mean depth})$$

Benefits analysis - Existing 405 hectare low-water pool in Lake Whittington has a weighted average water depth of approximately 2 m. Lowest weir elevation evaluated will create a permanent pool of 964 hectares with a weighted average water depth of 3 m; highest weir elevation evaluated will maintain a minimum of 1211 hectares and weighted average water depth of approximately 5 m.

Shallow water, 1-3 m, predominates under existing conditions, so sunfish habitat is relatively high (230 HU's) compared with that of silversides (65 HU's)(Fig. 4). At the lowest weir elevation, substantial increases in shallow and moderate depths, 4-8 m, occur and there are correspondingly substantial increases in habitat of both species. With successively increasing weir elevations, however, shallow water persists or increases slightly but moderately deep water increases linearly. As a result, sunfish habitat asymptotes at an intermediate weir elevation and silverside habitat increases linearly. Benefits expressed as gained HU's (and percentage increase over existing conditions) are:

Weir	Sunfishes	Silversides
110.0	436 (189%)	238 (366%)
112.5	540 (235%)	348 (535%)
115.0	587 (254%)	470 (723%)
117.0	590 (256%)	568 (874%)
119.5	561 (244%)	685 (1055%)

DISCUSSION

Multiple regression equations function similarly to HSI "blue book" equations, by providing measures of habitat quality based on multiple habitat variables (e.g., Stuber *et al.*, 1982). Multiple regression equations, however, offer several refinements, because they are empirical and do not entail *a priori* decisions regarding relationships between habitat parameters and fishes, thus reducing institutional bias. Use of multiple regression statistics allows the elimination of irrelevant variables from the final predictive model and quantification of the degree of correlation between habitat variables and fish communities (via correlation coefficients, and probability levels).

Models generated here are consistent with published accounts of fish habitat. Nine species of sunfishes occur in the oxbow lakes, but bluegill, *Lepomis macrochirus*, are numerically dominant (unpublished data). Bluegill, like most members of their genus, spawn preferentially in depths < 2 m (Breder, 1936; Robison and Buchanan, 1988). Silversides are found in littoral and pelagic habitats, apparently migrating into shallow areas during the day, offshore into deeper water at night (Mense, 1967; Hubbs, 1977).

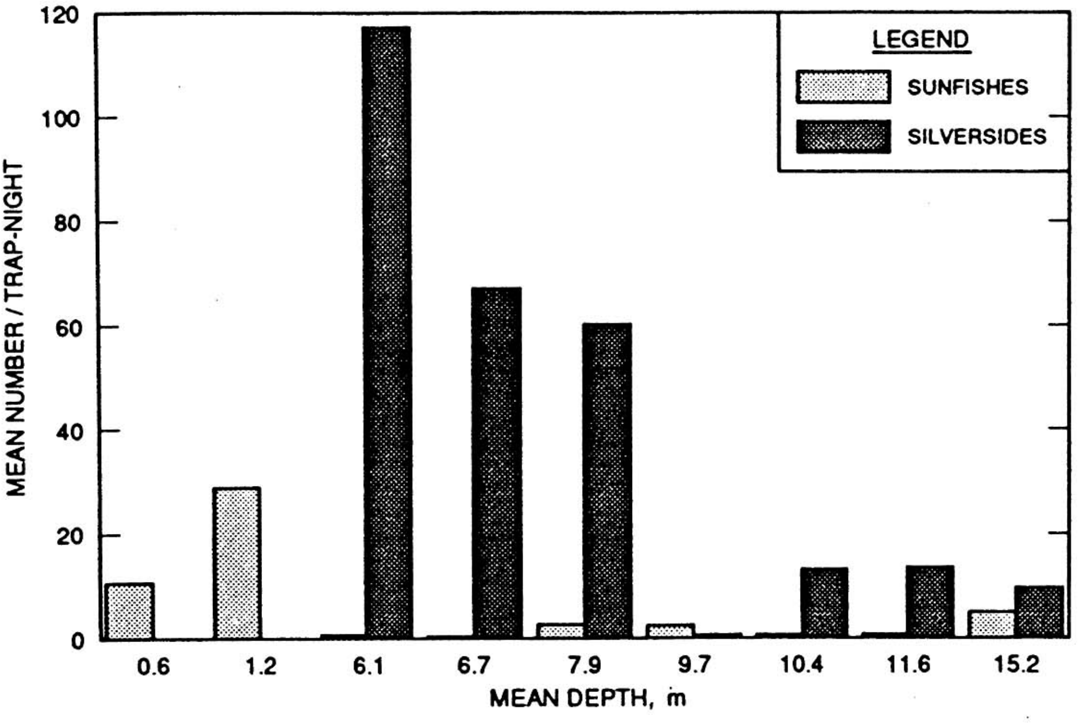

Fig. 2. Distribution of two taxa of fishes by lake depth; x-axis is not drawn to scale.

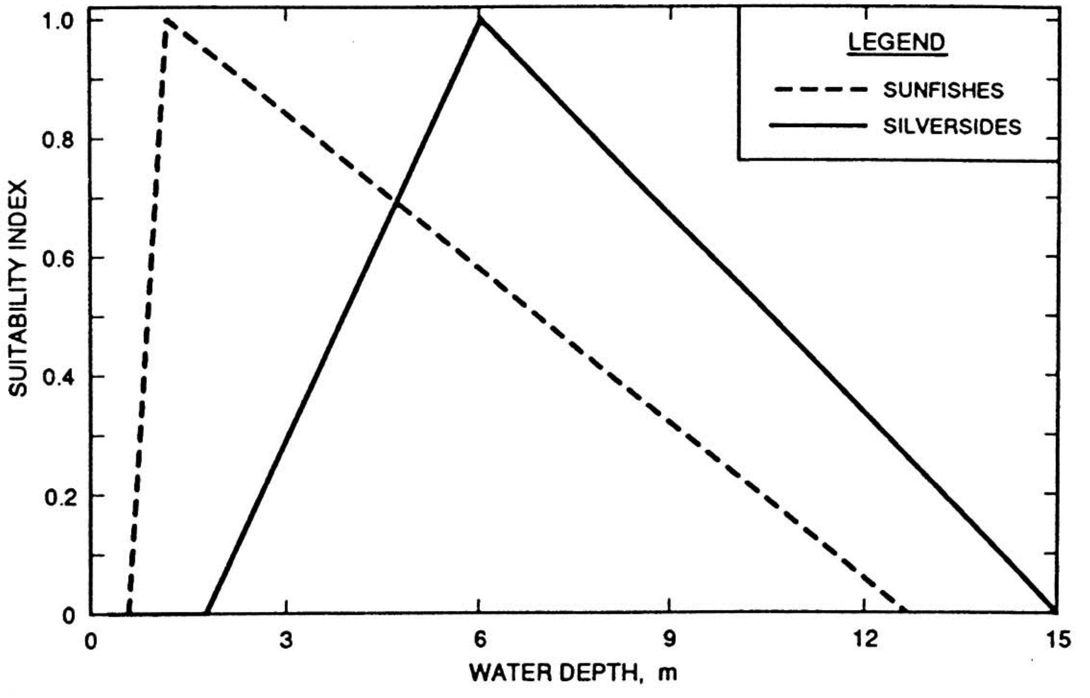

Fig. 3. Habitat suitability curves of lake depths for two taxa of fishes.

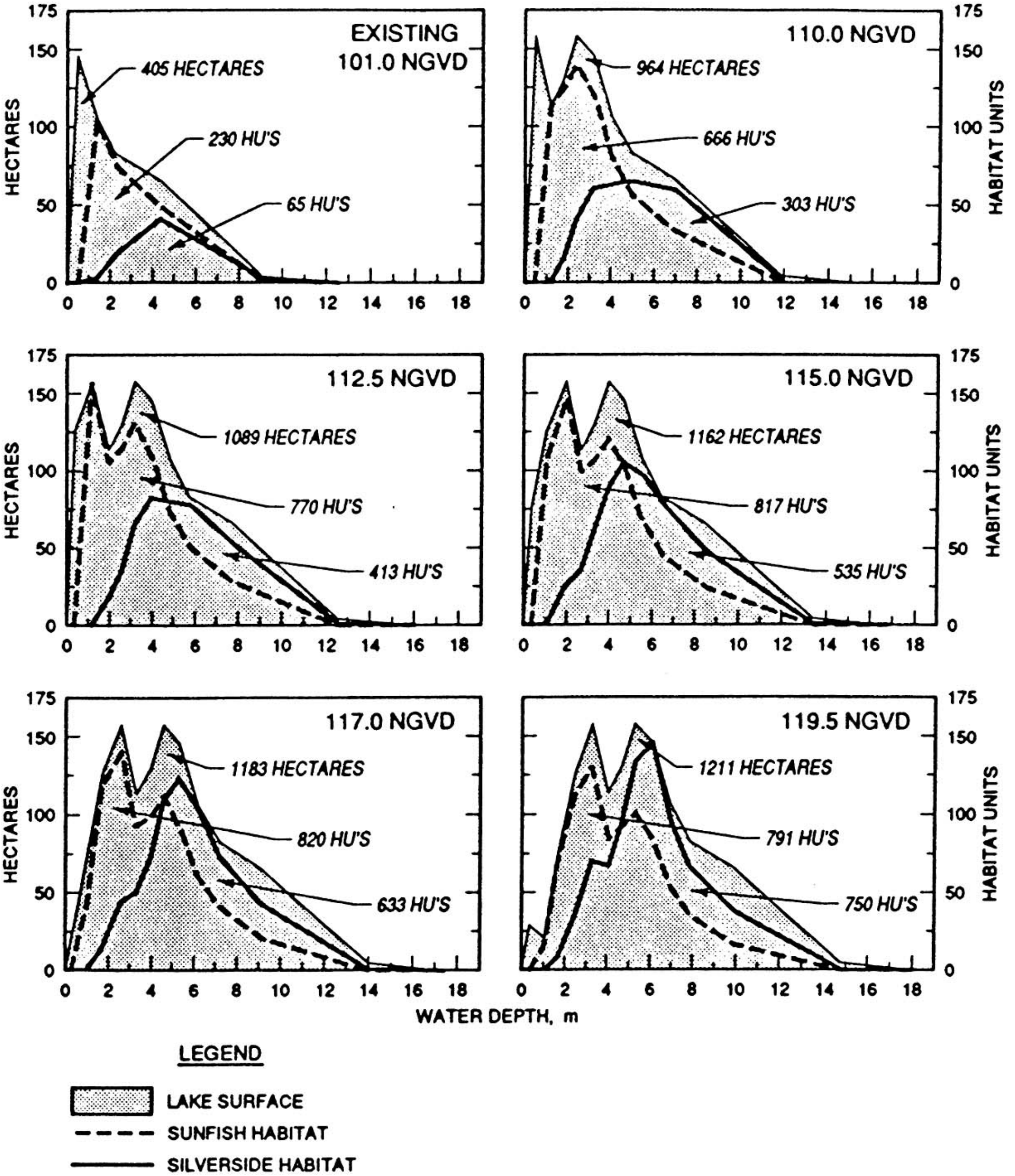

Fig. 4. Low water acreage and corresponding fish Habitat Units, by depth interval, for existing conditions and project alternatives. Total acreage and total Habitat Units for each taxon are indicated with each curve.

Pooled water in late summer will provide increased habitat for both taxa, probably resulting in higher numbers of fish, due to increased habitat volume, cooler temperatures, and increased production of zooplankton. Due to different depth preferences, benefits for the two taxa are maximized at different project alternatives. Drought negatively affects larval sunfishes less so than other taxa, but stable water levels in late season allow multiple spawnings following floods (Brown and Coon, 1994). An ecosystem-level simulation of environmental perturbations in Lake Texoma indicated that stabilized water levels, while affecting no other fish or fishery component, increased production of larvae (Patten et al., 1975). Conservatively, a weir height of 112.5' NGVD would provide near maximum habitat benefits for sunfish young-of-year, and a substantial increase for silversides.

Littoral densities of juveniles and adult fish (unpublished data), corresponding to those of larval fish (Table 1), suggest that increased acreages of shallow and moderately deep water from weir construction will not only result in greater spawning success of both groups, but that will translate into higher juvenile and adult fish densities. Shallow Lake Bolivar exhibits high littoral densities of sunfish (11.5/seine haul) and no silversides. Moderately deep Lake Beulah exhibits intermediate densities of sunfishes (8.3/seine haul) but maximum density of inland silversides (82.3/seine haul). Deeper Lake Whittington exhibits lowest density of sunfishes (4.2/seine haul), intermediate density of inland silversides (41.7/seine haul).

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