Evaluating Material Type and Configuration of Plastic Attractors on Fish Use in a Texas Reservoir

M. Todd Driscoll, *Texas Parks and Wildlife Department, 900 County Road 218, Brookeland, TX 75931*

J. Warren Schlechte, *Texas Parks and Wildlife Department, 5103 Junction Highway, Mountain Home, TX 78058*

Daniel J. Daugherty, *Texas Parks and Wildlife Department, 5103 Junction Highway, Mountain Home, TX 78058*

Sarah E. Haas, *Texas Parks and Wildlife Department, 4200 Smith School Road, Austin, TX 78744*

Abstract: State fisheries agencies are increasingly conducting habitat enhancement projects due to reservoir aging and associated habitat degradation, and evaluations of the effectiveness of habitat introductions are crucial to ensure desired results. Artificial habitat structures built from plastics may last for decades, yet their effectiveness has been variable—possibly due to construction materials, shape, and placement. During 2014 and 2016, we compared fish use of artificial structures built from two plastic types (PVC and plastic mesh) deployed in clustered or linear configurations in Sam Rayburn Reservoir, Texas, and we also compared methods (scuba versus fixed video camera) for evaluating fish use of the structures. We observed 14 fish species and 11,078 total fish during the study. Six centrarchids (bluegill [*Lepomis macrochirus*], spotted bass [*Micropterus punctulatus*], black crappie [*Pomoxis nigromaculatus*], longear sunfish [*L. megalotis*], largemouth bass [*M. salmoides*], and redear sunfish [*L. microlophus*]) comprised 99.5% of fish observed. Compared to cameras, scuba detected 1.7 times more species using the structures and also detected higher occupancy for nine of the 12 species-life stage (juvenile and adult) combinations of the six focal species and higher abundance for five of the 12 species-life stage combinations. Although both plastic structures were effective (mean = 42 and 17 fish per site for PVC and mesh, respectively), PVC structures attracted significantly more species, had higher overall abundance, had significantly greater abundances for five of 12 species-life stage combinations, and were more resistant to the degradation due to corrosion of anchor attachment hardware that was observed at all mesh sites and which had deteriorated to the point that they could not be sampled in 2016. Species richness, fish occupancy, and fish abundance did not vary with deployment configuration. Compared to 2014, 2016 had lower species richness, decreased occupancy for five species, and lower abundance for three species. Our results suggest that plastic structures are effective at attracting high numbers of fish, but plastic type can influence species richness, fish occupancy, fish abundance, and attractor durability. Although plastic attractors can have greater structural longevity, future research should focus on materials, configuration, and effectiveness over time.

Key words: habitat enhancement, abundance, occupancy, camera, scuba

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Governmental fisheries agencies first introduced habitat structures to increase cover availability for fish in the 1930s (Hazzard 1937, Rodeheffer 1939). By the 1970s, the addition of fish habitat was common throughout the United States in a variety of waters, although many of these introductions occurred without well-defined goals or expected results (Bolding et al. 2004). More recently, a 1999 survey found that 82% of state fisheries agencies conducted some type of habitat enhancement and the most common objective was to concentrate fish and increase angler catch rates (Tugend et al. 2002). Man-made reservoirs are often the target of habitat introductions, as existing cover is often cleared prior to reservoir construction and any remaining natural habitat, of course, decomposes through time (Miranda 2017). Loss of reservoir habitat from age-related decomposition has been rapid throughout the United States, where the median reservoir age exceeds 50 years (Miranda et al. 2010). As reservoir fisheries managers add structure in response to declining habitat, further understanding of the effectiveness of these introductions is crucial to ensure desired results.

Historically, a wide variety of structural material has been used for constructing fish habitat (e.g., natural woody debris, stone, tires, cinder blocks, and synthetic plastic materials; Bolding et al. 2004, Miranda 2017). It is well-established that many introduced materials attract fish (Brown 1986, Bolding et al. 2004), particularly benthic (e.g., catfishes [Ictaluridae]) or structure-oriented species (e.g., sunfishes [Centrarchidae]; Walters et al. 1991). However, structure effectiveness can be related to its complexity and amount of interstitial space (Lynch and Johnson 1989, Walters et al. 1991, Daugherty et al. 2011), shape and size (Daugherty et al. 2014), and structure material (Magnelia et al. 2008, Baumann et al. 2016).

Natural woody debris is often available at low expense and can provide desired interstitial spaces, but degradation can be relatively rapid (Wilbur 1978, Walters et al. 1991, Daugherty et al. 2014). Structures made of plastic materials are lightweight, relatively easy to deploy, and may be less likely to snag fishing tackle. Most importantly, plastic structures may last for decades and can be more effective at concentrating fish than natural structures (Rodgers and Bergersen 1999, Baumann et al. 2016). Baumann et al. (2016) determined that three different configurations of plastic structures attracted similar numbers of fish compared to natural woody debris during the first two years after placement; however, by year three, the polyvinyl chloride (PVC) pipe/corrugated hose structure attracted 411% more fish than natural structures, likely because of degradation of natural structure, and 84% and 156% more fish than the other two plastic structure configurations evaluated.

Despite the numerous studies examining the effectiveness of introduced structures to attract fish, potential effects of attractor shape or deployment configuration on effectiveness is rarely examined. Daugherty et al. (2014) found that bluegill (*Lepomis macrochirus*) abundance was higher in cluster-shaped, natural woody debris attractors compared to linear-shaped attractors. However, bluegill size was smaller in the clustered structures, suggesting that this configuration provided a predation refuge for smaller fish.

Building on the results of Daugherty et al. (2014), we examined potential effects of plastic structure material (PVC/corrugated pipe vs. plastic mesh) as well as deployment configuration (clustered or linear) of the plastic structures on fish occupancy, species richness, abundance, and size structure in Sam Rayburn Reservoir, Texas. Attractors constructed of PVC/corrugated pipe have been proven to attract fish (Baumann et al. 2016), but are relatively expensive to construct (US$125–175 per structure). In contrast, plastic mesh structures cost far less ($60 per structure) and provide more interstitial spaces, but their effectiveness has not been evaluated.

We also compared the effectiveness of two sampling gears (scuba and fixed camera) for evaluating the use of the structures by fish. Using scuba gear to sample fish attractors is common (Prince and Maughan 1979, Graham 1992, Magnelia et al. 2008), but we hypothesized that a camera could provide a more rapid, less costly sampling alternative without the inherent safety risks of scuba diving.

Study Site

Sam Rayburn Reservoir is an impoundment of the Angelina River in southeastern Texas. The U.S. Army Corps of Engineers constructed the reservoir in 1966 for flood control, generation of hydroelectric power, water supply, and recreational uses (Driscoll and Ashe 2015). At conservation pool, the reservoir is 45,091 surface ha with a shoreline length of 1207 km and mean depth of 6.1 m. Water-level fluctuations average 1.8 m annually, and the reservoir is eutrophic and moderately clear (Secchi range 1–3 m). Reservoir habitat consists of standing timber and aquatic vegetation that is primarily hydrilla (*Hydrilla verticillata*) and American lotus (*Nelumbo lutea*); coverage ranged from 1% to 12% of reservoir surface area since 2006. The reservoir is thermally stratified annually from May to October; depth of the metalimnion is 9–10 m and the hypolimnion is anoxic from July to October. The reservoir supports a high-use recreational fishery (i.e., annual fishing effort in excess of 800,000 h) that is economically important to the region ($47.1 million annual value; Driscoll and Myers 2013). Primary sport fishes are largemouth bass (*Micropterus salmoides*), black crappie (*Pomoxis nigromaculatus*), blue catfish (*Ictalurus furcatus*), and channel catfish (*I. punctatus*). Threadfin shad (*Dorosoma petenense*) and bluegill are the principal prey fishes.

Methods

We constructed our polyvinyl chloride structures (Figure 1) using 38-mm diameter PVC pipe frames (0.9 x 0.9 x 1.8-m in dimension), with approximately 45 m of 102-mm diameter corrugated hose randomly wrapped around the frames. Approximately every 40 cm, 13-mm holes were drilled in the frames to assist with sinking and stability on the reservoir bottom. Our PVC structure was similar to an attractor designed by the Georgia Department of Natural Resources that was evaluated by Baumann et al. (2016). We built our plastic mesh structures (Figure 1) in a manner meant to mirror the design of the PVC structures (i.e., equal frame dimension and length of material wrapped around the frame): we constructed the frames using 51-mm diameter pipe and wove industrial plastic mesh around and among the pipes. We designed two deployment configurations: clustered (six structures arranged in a compact rectangle) and linear (six structures arranged end-to-end). This 2 x 2 factorial design required four experimental site arrangements (PVC-clustered, PVC-linear, mesh-clustered, mesh-linear). Three replicates of each treatment were used, resulting in 72 individual structures deployed at 12 sites. Divers placed the structures in either clustered or linear arrangements at the 12 study sites; they secured the structures to each other with plastic zip ties in order to minimize movement and to maintain the desired configuration. Divers further anchored each plastic structure with four 14-kg concrete blocks attached to the structures with 5-mm diameter stainless steel cable and aluminum clasps.

Similar to methods described by Magnelia et al. (2008), we chose experimental sites void of natural cover but which had other features conducive for sportfish attraction (i.e., underwater points or areas adjacent to steep contour breaks). All structures were placed at the 5- to 6-m depth contours (i.e., above the normal metalimnion during summer months) in the lower third of the reservoir (where water clarity was highest). Structure sites were unmarked to minimize the chance of angler disturbance.

Utilizing both scuba divers and a fixed, underwater camera, we

Figure 1. Plastic mesh (left) and polyvinyl chloride (PVC) (right) fish attractors (0.9- x 0.9- x 1.8-m frames with approximately 45 m of internal material) evaluated at Sam Rayburn Reservoir, Texas, in 2014 and 2016.

sampled fishes occupying each plastic attractor site. Divers used methods similar to those described by Graham (1992) to count and identify fish. A diver descended to each experimental site and then waited 5 min before counting to minimize disturbance effects of fish displacement due to the diver's own descent. Diver location relative to the structures was random, except that they were instructed to avoid sampling from the corners (clustered) or ends (linear) of sites where sight lines might not be clear. Diver movement was minimal after sampling position, diver on knees approximately 1 m from structures, was achieved. The diver first estimated abundance of each species by scanning left and right on a 180-degree plane. A separate 180-degree scan and count was conducted for each species observed. Once all observed species were counted, this was considered a replicate. Five total replicates were conducted at each site on a given survey date with a 3-min delay between counts. Means for the five replicates at each site were used for statistical analyses. To ensure sampling consistency, the same diver conducted all fish counts at all sites throughout the duration of the study. During each count the diver categorized fish as either juveniles or adults using pre-determined length cutoffs (sunfishes = 76 mm, black basses = 254 mm, and crappies = 177 mm).

The underwater video camera (760CZ Series with 10-inch color monitor and 92-degree viewing angle; AquaVu, Crosslake, Minnesota) was secured on a metal tripod, then lowered to each site. Camera location was as described for scuba methods. To facilitate comparison with scuba counts, a diver ensured proper camera orientation and equal distance from structures as that for scuba (approximately 1 m). A single 5-min video was recorded via an attached DVR beginning 5 min after the diver surfaced. The video was observed in the laboratory, and total numbers of fish by species and size (juvenile and adult) were counted.

During 2014, all sites were sampled monthly from June to September using both scuba and underwater camera. Each month, sampling occurred over four total days (consecutive if possible, unless there were weather-related delays or scheduling conflicts). Each day, 6 of 12 sites were sampled (unless weather or equipment failures restricted sampling) by alternating scuba and camera gears among sites (i.e., three sites were sampled by each gear per day). Sampling was conducted from 1000 – 1500 hours each day to maximize underwater visibility. Sampling during the same period was scheduled for 2015, but extremely high water had sites below the thermocline until July, so sampling was cancelled for that year. During June 2016 (two years post-deployment), all sites were examined for structural integrity prior to sampling, and we observed considerable galvanic corrosion of the anchor attachment hardware, sufficient to lose connection to the majority of the anchors. All of the PVC sites remained completely intact; however, all of the plastic mesh sites had lost at least some of the individual structures. Thus, only PVC sites were sampled in that year, again monthly from July to September (six total sites, with sampling dispersed over 1–2 days per month). In addition, 2016 sampling only included scuba counts, as preliminary analyses of the 2014 camera data indicated that scuba counts resulted in higher species richness and fish abundance.

To quantify fish attraction of the two plastic types and configurations of artificial structures, we created three response variables (measured for all sites across survey dates): species richness (the number of fish species observed at a site), fish occupancy (fish presence/absence), and fish abundance (the total number of fish). In addition to analyzing each response of the entire species assemblage, we also conducted species-specific analyses for fish occupancy and abundance on both juveniles and adults. Predictor variables included in the analyses were plastic type (PVC or mesh), configuration (linear or clustered), sampling gear (scuba or camera), and sampling year. We included sampling month in the model as a blocking variable to reduce unexplained variability. In addition to having plastic type and configuration as main effects, we also explored the interaction of the two variables.

We used regression-based procedures (i.e., glm, lm, and logisticf) in R statistical software version 3.5.2 (R Development Core Team 2014) to conduct the various analyses. We used these regression procedures because they provided flexibility to fit various distributional assumptions associated with our response variables. In all analyses, our predictor variables were categorical. Thus, although regression procedures were used, the models we fit were ANOVA models (Neter et al. 1996). Species richness and abun-

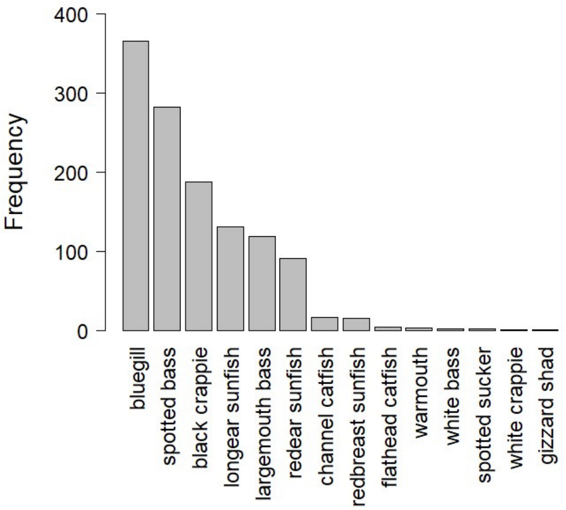

Figure 2. Total numbers of fish observed by species from plastic fish attractors in Sam Rayburn Reservoir, Texas, in 2014 and 2016.

Table 1. Comparison of mean fish occupancy estimates from scuba and camera sampling. For juvenile black crappie and redear sunfish, lack of observed occupancy using the camera resulted in non-convergence of the statistical algorithm. Differences in the residual degrees of freedom result from whether the final model retained significant block effects associated with months.

Life stage	Species	Camera (SE)	Scuba (SE)	*Z*-value	Residual df	*P*-value
Juveniles	Black crappie	0.00	0.01 (0.01)	–	–	–
	Bluegill	0.60 (0.07)	0.85 (0.04)	3.213	99	0.001
	Longear sunfish	0.02 (0.02)	0.43 (0.06)	3.814	95	<0.001
	Redear sunfish	0.00	0.12 (0.04)	–	–	–
	Largemouth bass	0.04 (0.03)	0.22 (0.05)	2.726	99	0.006
	Spotted bass	0.57 (0.07)	0.74 (0.05)	3.399	99	<0.001
Adults	Black crappie	0.47 (0.07)	0.68 (0.05)	2.326	95	0.020
	Bluegill	0.85 (0.05)	0.89 (0.04)	0.917	99	0.367
	Longear sunfish	0.02 (0.02)	0.43 (0.06)	3.463	95	<0.001
	Redear sunfish	0.04 (0.03)	0.41 (0.06)	3.877	95	<0.001
	Largemouth bass	0.32 (0.07)	0.47 (0.06)	2.554	95	0.011
	Spotted bass	0.55 (0.07)	0.78 (0.05)	3.657	99	<0.001

Table 2. Comparison of mean fish abundance estimates from scuba and camera sampling. For juvenile black crappie, lack of observed abundance resulted in non-convergence of the statistical algorithm. For all tests, df = 1, 95.

Life stage	Species	Camera (SE)	Scuba (SE)	*F*-value	*P*-value
Juveniles	All species	10.51 (1.68)	10.66 (1.48)	4.423	0.038
	Black crappie	0.00	0.00	–	–
	Bluegill	7.23 (1.56)	8.12 (1.29)	4.550	0.036
	Longear sunfish	0.02 (0.02)	0.88 (0.25)	9.635	0.003
	Redear sunfish	0.00	0.11 (0.06)	2.427	0.123
	Largemouth bass	0.04 (0.03)	0.09 (0.03)	4.105	0.046
	Spotted bass	3.21 (0.65)	1.46 (0.23)	3.463	0.066
Adults	All Species	31.62 (4.64)	13.93 (1.47)	15.745	<0.001
	Black crappie	4.09 (1.30)	2.36 (0.54)	2.344	0.129
	Bluegill	24.36 (4.33)	9.15 (1.17)	12.595	<0.001
	Longear sunfish	0.04 (0.04)	0.63 (0.15)	7.113	0.009
	Redear sunfish	0.04 (0.03)	0.36 (0.07)	10.304	0.002
	Largemouth bass	1.09 (0.49)	0.52 (0.15)	0.314	0.577
	Spotted bass	1.81 (0.49)	0.78 (0.10)	2.924	0.091

dance were examined using linear regression models with a normal error distribution, whereas occupancy was assessed using logistic regression models with a binomial error distribution. Quasi-complete separation is a common occurrence in occupancy models with numerous categorical variables, which can result in failed model convergence (Heinze and Schemper 2002). We experienced this in some of our occupancy models and attempted to circumvent the convergence issue by using Firth's (1993) penalized likelihood correction technique (i.e., the "logisticf" R-package; Heinze et al. 2018). Because camera surveys and plastic mesh structures were not used in 2016, analyses on gear and plastic type used data collected in 2014 only. In contrast, analyses on configuration and year effects used data from both 2014 and 2016. All statistical analyses were considered significant at $P \leq 0.05$.

Results

A total of 121 sampling events were conducted at attractor sites during 2014 and 2016. This included 74 scuba and 47 camera samples, 70 PVC and 51 plastic mesh samples, and 59 clustered and 62 linear samples. Fourteen fish species and 11,078 total fish were observed during the study period (Figure 2). The six most prevalent species (bluegill, spotted bass [*Micropterus punctulatus*], black crappie, longear sunfish [*Lepomis megalotis*], largemouth bass, and redear sunfish [*L. microlophus*]) comprised 99.5% of fish sampled and were included in the species-specific occupancy and abundance models.

Sampling Gears

On average, scuba sampling detected more species (4.41, SE = 0.20) than the camera (2.66, SE = 0.15; $F = 76.07$; df = 1, 95; $P <$ 0.001). Scuba sampling also resulted in higher occupancy for nine of the 12 species-life stage (juvenile and adult) combinations of the six focal species (Table 1), and higher abundance for five of the 12 combinations (Table 2). Combining species, scuba gear sampled a

Table 3. Comparison of mean fish occupancy estimates from PVC and plastic mesh fish attractors. Inadequate sample size prevented analysis of juvenile black crappie. Differences in the residual degrees of freedom result from whether the final model retained significant block effects associated with months. For juvenile redear sunfish, an additional degree of freedom occurs due to non-convergence if sampling gear was retained in the model.

Life stage	Species	PVC (SE)	Mesh (SE)	*Z*-value	Residual df	*P*-value
Juveniles	Black crappie	0.01 (0.01)	0.00	–	–	–
	Bluegill	0.87 (0.04)	0.59 (0.07)	3.523	99	<0.001
	Longear sunfish	0.40 (0.06)	0.10 (0.04)	3.789	95	< 0.001
	Redear sunfish	0.09 (0.03)	0.06 (0.03)	–0.032	100	0.974
	Largemouth bass	0.11 (0.04)	0.20 (0.06)	–0.968	99	0.333
	Spotted bass	0.57 (0.06)	0.82 (0.05)	–2.141	99	0.032
Adults	Black crappie	0.73 (0.05)	0.41 (0.07)	3.661	95	<0.001
	Bluegill	0.94 (0.03)	0.78 (0.06)	2.503	99	0.013
	Longear sunfish	0.46 (0.06)	0.02 (0.02)	3.763	95	<0.001
	Redear sunfish	0.29 (0.05)	0.24 (0.06)	0.391	95	0.671
	Largemouth bass	0.36 (0.06)	0.49 (0.07)	–1.244	95	0.213
	Spotted bass	0.66 (0.06)	0.75 (0.06)	–0.305	99	0.761

Table 4. Comparison of mean fish occupancy estimates for 2014 and 2016 from PVC fish attractors sampled with scuba. Differences in the residual degrees of freedom result from whether the final model retained significant block effects associated with months.

Life stage	Species	2014 (SE)	2016 (SE)	*Z*-value	Residual df	*P*-value
Juveniles	Black crappie	0.00	0.06 (0.06)	1.599	44	0.450
	Bluegill	0.93 (0.05)	0.78 (0.10)	–1.456	44	0.145
	Longear sunfish	0.69 (0.09)	0.39 (0.12)	–2.699	40	0.007
	Redear sunfish	0.10 (0.06)	0.17 (0.09)	0.645	44	0.519
	Largemouth bass	0.21 (0.08)	0.06 (0.06)	–1.332	44	0.183
	Spotted bass	0.79 (0.08)	0.33 (0.11)	–3.024	44	0.003
Adults	Black crappie	0.86 (0.07)	0.61 (0.12)	–1.921	40	0.055
	Bluegill	0.97 (0.03)	0.83 (0.09)	–1.437	44	0.151
	Longear sunfish	0.69 (0.09)	0.61 (0.12)	–1.424	40	0.154
	Redear sunfish	0.48 (0.09)	0.33 (0.11)	–1.901	40	0.057
	Largemouth bass	0.52 (0.09)	0.28 (0.11)	–1.829	40	0.067
	Spotted bass	0.97 (0.03)	0.44 (0.12)	–3.172	44	0.002

higher abundance of juveniles, while the camera resulted in more adults. For juvenile black crappie, lack of observed abundance resulted in non-convergence of the statistical algorithm. Use of the Firth's penalized likelihood approach did not resolve this issue.

Species Richness

We saw higher species richness on PVC fish attractors (4.03; SE = 0.22) than we did on plastic mesh structures (3.31, SE = 0.20; F = 13.34; df = 1, 95; P < 0.001). Model-estimated average species richness using scuba gear was 4.66 (SE = 0.20) for PVC structures in 2014. Species richness declined to 3.61 (SE = 0.54) species in 2016 (F = 19.90; df = 1, 112; P < 0.001). The configuration of the structure did not affect species richness (clustered = 3.81, SE = 0.24; linear = 3.65, SE = 0.20; F = 0.66; df = 1, 112; P = 0.42).

Fish Occupancy

Most sites (97.5%) were occupied by at least some fish. We found that occupancy was higher for bluegill and longear sunfish (both juveniles and adults) and adult black crappie at PVC attractors, whereas juvenile spotted bass showed increased occupancy at mesh structures (Table 3). We again had convergence issues with juvenile black crappie; we recorded one juvenile black crappie, and it appeared on a PVC structure. Occupancy was higher in 2014 when compared to 2016 for juvenile longear sunfish and spotted bass (juveniles and adults) (Table 4). The configuration of the structure did not affect fish occupancy for any of the 12 combinations of species and life stage (Z range = -1.226 to 0.974; P > 0.10).

Fish Abundance

Combining species, PVC sites had higher overall abundance (41.72, SE = 3.94) than mesh sites (17.23, SE = 2.02; F = 6.33; df = 1, 117; P < 0.001), and higher abundance for both juveniles and adults (Table 5). For juvenile populations, PVC sites had higher abundance of bluegill and longear sunfish, whereas spotted bass abundance was higher at mesh sites. Abundance of adult black crappie, bluegill, and longear sunfish was also higher at PVC structures, but adult largemouth bass abundance was higher on mesh structures. On average, sites had 39.06 (SE = 4.20) individuals on PVC structures and 17.24 (SE = 2.02) on mesh in 2014. In 2016, overall abundance at PVC structures declined to 14.03 (SE = 3.10; F = 4.67; df = 1, 117; P < 0.001). Mesh sites were not sampled due to degradation. Abundance was higher in 2014 than 2016 for juveniles and adults (species combined), and for juvenile longear sunfish, adult largemouth bass, bluegill, and spotted bass (juveniles and adults) (Table 6). Similar to results for fish occupancy, the configuration of the structure did not affect fish abundance for any species or life stage (F range = 0.03 to 1.86; P > 0.10).

Table 5. Comparison of mean fish abundance estimates from PVC and plastic mesh fish attractors. Inadequate sample size prevented analysis of juvenile black crappie. For all tests, df = 1, 95.

Life stage	Species	PVC (SE)	Mesh (SE)	*F*-value	*P*-value
Juveniles	All species	12.82 (1.75)	7.56 (0.98)	21.530	<0.001
	Black crappie	0.00	0.00	–	–
	Bluegill	10.43 (1.55)	4.12 (0.79)	26.01	<0.001
	Longear sunfish	0.90 (0.27)	0.06 (0.03)	10.765	0.002
	Redear sunfish	0.04 (0.02)	0.10 (0.08)	1.004	0.319
	Largemouth bass	0.05 (0.02)	0.10 (0.04)	0.619	0.433
	Spotted bass	1.38 (0.30)	3.18 (0.54)	4.452	0.037
Adults	All species	28.90 (3.27)	9.68 (1.32)	48.136	<0.001
	Black crappie	4.65 (0.99)	0.81 (0.25)	12.967	<0.001
	Bluegill	22.11 (3.00)	5.39 (1.04)	39.968	<0.001
	Longear sunfish	0.69 (0.16)	0.01 (0.01)	15.603	0.001
	Redear sunfish	0.27 (0.07)	0.19 (0.06)	0.066	0.798
	Largemouth bass	0.22 (0.05)	1.45 (0.49)	6.027	0.016
	Spotted bass	0.74 (0.16)	1.78 (0.41)	3.007	0.086

Table 6. Comparison of mean fish abundance estimates for 2014 and 2016 from PVC fish attractors sampled with scuba. For all tests, df = 1, 40.

Life stage	Species	2014 (SE)	2016 (SE)	*F*-value	*P*-value
Juveniles	All species	17.88 (3.10)	3.04 (0.71)	33.733	<0.001
	Black crappie	0.00	0.01 (0.01)	1.261	0.268
	Bluegill	14.29 (2.78)	2.33 (0.58)	24.157	<0.001
	Longear sunfish	1.92 (0.59)	0.36 (0.14)	11.042	0.002
	Redear sunfish	0.03 (0.02)	0.10 (0.08)	0.479	0.493
	Largemouth bass	0.08 (0.03)	0.02 (0.02)	2.437	0.126
	Spotted bass	1.54 (0.34)	0.22 (0.12)	21.132	<0.001
Adults	All species	21.19 (2.65)	10.99 (2.44)	11.512	0.002
	Black crappie	4.38 (1.22)	1.81 (0.65)	1.806	0.187
	Bluegill	14.02 (2.21)	7.54 (1.87)	8.791	0.005
	Longear sunfish	1.10 (0.34)	0.79 (0.22)	3.014	0.090
	Redear sunfish	0.39 (0.11)	0.42 (0.17)	0.848	0.363
	Largemouth bass	0.30 (0.10)	0.10 (0.05)	4.889	0.033
	Spotted bass	0.85 (0.14)	0.19 (0.06)	16.185	<0.001

Discussion

We found that scuba gear detected significantly more species and resulted in higher occupancy and relative abundance for most combinations of fish species and life stages. Although estimating fish abundance with scuba gear is common and effective when evaluating fish attractors due to its direct observations, rapid estimation, and versatility with structure size and depth (Prince and Maughan 1979, Graham 1992, Magnelia et al. 2008, Thurow et al. 2012), scuba requires certification, has inherent safety risks (Dolloff et al. 1996), and the required gear can be cost-prohibitive. In contrast, underwater cameras provide a potentially safer, more economical, and less labor-intensive sampling method. We suspect that higher counts from scuba resulted primarily from the wider 180-degree sampling view from the diver, as compared to the narrower, 92-degree fixed camera view, especially as visibility for fish detection was similar for both scuba and camera sampling. Initially, we hypothesized that the camera sampling would work better than scuba, even with the smaller field of view, as fish can exhibit diver avoidance during scuba sampling (Stanley and Wilson 1995). However, our study required a diver to place the camera equidistant from the structures to that for scuba counts for comparison. Diver presence could have displaced fish from structures and negatively affected camera counts, even though we waited five minutes after the diver resurfaced to begin sampling. Nonetheless, our results indicated that scuba was the more effective sampling gear. We suggest that our inexpensive ($600) camera collected sufficient data to potentially provide a safer, cost-effective alternative for general fish attractor monitoring (i.e., overall fish use and structure longevity) when absolute species richness or fish community data is not essential. Further advances in optics may allow for comparable collection in the future. Multi-beam imaging sonar can also be a viable and effective method of sampling attractors, especially in turbid reservoirs (Baumann et al. 2016), and can also eliminate the safety risks of scuba sampling. However, sonar equipment also is more expensive (about $2,000) and lacks the ability to definitively identify most species.

Baumann et al. (2016) found that plastic fish attractors built from PVC pipe and corrugated hose were effective at attracting fish (mean = 63 fish per site). Our plastic attractors that were comparable in design to Baumann et al. (2016) were likewise effective, attracting a mean of 42 and 17 fish per site for PVC and mesh sites, respectively. Fish found around attractors were primarily centrarchids (99% of samples), similar to results from numerous other studies examining the effects of introduced habitat (Prince and Maughan 1978, Walters et al. 1991, Rold et al. 1996, Magnelia et al. 2008, Daugherty et al. 2014). Rold et al. (1996) and Magnelia et al. (2008) found low numbers of fish associated with plastic structures (approximately four fish per attractor), but their structures were constructed of smaller diameter material (ribbon-like strands and 19-mm diameter pipe, respectively). Similar to our study, Magnelia et al. (2008) conducted their study in a relatively productive Texas reservoir, but the Rold et al. (1996) study was conducted in a relatively new 23-ha strip mine impoundment that likely had lower fish abundance compared to our study reservoir, contributing to lower observed fish use.

Regardless, our structures offered greater surface volume and diameter, which may have resulted in higher periphyton growth and available shade, potentially increasing their effectiveness. Periphyton abundance may increase attractor effectiveness because many fish species directly consume periphyton or the invertebrates that feed on it (Van Dam et al. 2002, Smokorowski et al. 2006). Helfman (1981) and Cocheret de la Moriniere et al. (2004) suggested that shade attracts fish because it provides similar advantages as structure (i.e., shelter to escape predation, and ambush points for predators). Larger attractor sites may support higher numbers of fish (Lynch and Johnson 1989), similar to what has been found for natural and artificial reefs in marine environments (Schroeder 1987, Rountree 1989). However, few studies have documented the effects of attractor size in freshwater bodies. Although our plastic attractor sites were nearly three times larger in volume (9.2 m^3) than those from Baumann et al. (2016; 3.5 m^3), we observed 30% to 70% fewer fish. Daugherty et al. (2014) found higher occupancy rates for largemouth bass from larger structures, but electrofishing catch rates for bluegill and largemouth bass were higher in smaller structures.

Our PVC fish attractor design was adopted from Baumann et al. (2016), which was found to concentrate significantly more fish when compared to two other plastic designs and natural woody debris attractors. Similarly, when we compared our PVC sites to those constructed of industrial mesh plastic, we found that PVC structures attracted significantly more species, had higher overall abundance, and had greater abundances for five of the 12 combinations of species and life stages. Mesh plastic was examined in our study primarily due to its increased interstitial spacing that can increase structure effectiveness (Lynch and Johnson 1989, Walters et al. 1991). However, only juvenile spotted bass and adult largemouth bass abundance was higher at mesh plastic sites. Even though black basses are the most popular sport fishes at Sam Rayburn Reservoir (Driscoll and Ashe 2015) and many other U.S. waters (U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau 2006), we recommend use of PVC structures over mesh plastic due to the increased overall effectiveness and durability of PVC plastic, despite their more expensive construction costs. Our PVC structures were made of solid-walled pipe, which were less likely to snag fishing lures, and were less buoyant (i.e., more stable) than mesh plastic attractors. The increased buoyancy of mesh plastic (coupled with galvanic corrosion of anchor attachment hardware composed of two different metals) was the primary reason for degradation that prevented sampling of mesh sites during 2016. Even without concrete anchors, the PVC structures were all completely intact. However, the mesh plastic was buoyant enough to float to the surface immediately after anchor loss. Potential buoyancy of materials and appropriate anchoring hardware are important considerations relative to durability and longevity of plastic structures. When using PVC or other hollow plastic pipe, holes should be drilled to facilitate sinking and bottom stability.

Daugherty et al. (2014) found that attractor structures composed of recycled Christmas trees configured in cluster-shaped structures attracted higher numbers of smaller bluegill and largemouth bass than linear-shaped attractors. The authors concluded that cluster-shaped attractors were preferred as protective cover from predation due to the increased interior space that likely reduces encounters with predators, which was also deduced by Crowder and Cooper (1979). However, in our study we found no evidence of any effects related to fish attractor configuration. Although the plastic structures in our study were not as interstitially complex as the Christmas tree attractors from Daugherty et al. (2014), ours did attract juvenile fish that may have been using the structures as a predation refuge. Moreover, our clustered structures did provide increased interior space. Nonetheless, we found no effects of deployment configuration on species richness, fish occupancy, or fish abundance.

Undoubtedly, longevity is an advantage of using plastic materials to construct fish attractors (Rodgers and Bergersen 1999, Bolding et al. 2004, Baumann et al. 2016). Although larger conifer and hardwood logs (20–30 cm in diameter) can persist for at least five years after deployment (Bilby et al. 1999), degradation of natural woody debris can be rapid (Wilbur 1978, Walters et al. 1991) and can reduce structure effectiveness within the first year after deployment (Daugherty et al. 2014). We examined our PVC fish attractors over a period of three years and observed no degradation or physical disturbances at any of these sites. Initially, we hypothesized that both our PVC and mesh plastic fish attractors would increase in effectiveness over the study period, due to the gradual growth of periphyton and associated recruitment of invertebrates that likely attract fish (Van Dam et al. 2002, Smokorowski et al. 2006). However, species richness, overall abundance for juveniles and adults (species combined), and abundance for four species significantly declined from 2014 to 2016 at PVC attractors. Periphyton appeared to reach its maximum biomass rapidly, as we did not observe any change in coverage from three months post-deployment in 2014 until the end of sampling in 2016. We expected our fish attractors to have been more effective in 2016 due to the significant decline in hydrilla coverage resulting from high water levels in 2015. Thus, factors causing decreased attractor usage during our three-year study period are not understood. Even though our attractor sites were not visibly marked, anglers located them via global positioning system chartplotters and sonar. Discussions with fishing guides indicated that our attractor sites were heavily fished throughout the study period, and that their angling catch rates also declined over time. Thus, consistently high angling effort and related harvest at our fish attractor sites may have attributed to observed declines. Fish recolonization rates of areas or attractors in response to harvest have been little studied but should be investigated.

Consistent with previous studies, our results highlight the observation that PVC fish attractors can provide effective attraction for centrarchids in reservoirs. Although PVC attractors have increased structural longevity, our results indicated generally declining effectiveness over the course of the study period. To date, no studies have assessed long-term trends in fish use of artificial structures. Longer term evaluations are needed to better understand temporal trends related to structure effectiveness.

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