Effects of Reservoir Characteristics on Crappie Populations in Small Southern Impoundments

Bryant M. Haley[1], *Department of Wildlife, Fisheries & Aquaculture, Mississippi State University, Box 9690, Mississippi State, MS 39762*

J. Wesley Neal, *Department of Wildlife, Fisheries & Aquaculture, Mississippi State University, Box 9690, Mississippi State, MS 39762*

Abstract: Crappie (*Pomoxis* spp.) fisheries are important across much of North America, but most research has focused on management in larger reservoirs. Understanding factors that affect crappie populations in small reservoirs could improve management approaches because manipulation of physicochemical, biological, and morphometric factors may be feasible in these smaller systems. We examined biotic and abiotic features that influence crappie (black crappie *P. nigromaculatus* and white crappie *P. annularis*) species dominance, growth, condition, and trap net catch-per-effort (CPE) in 16 small southern U.S. reservoirs (28–357 ha). Morphometric and physical habitat characteristics, water quality variables, and fish community characteristics were compared to crappie population metrics using an ordination approach. Reservoirs varied considerably in morphometrics, physicochemical environment, and fish communities, as well as in crappie population dynamics. Reservoir maximum and relative depth and productivity as measured by chlorophyll-a was associated with crappie species composition, as white crappie were more common in shallow and more productive systems and black crappie were associated with deeper systems with greater water transparency. Growth was faster in deeper reservoirs and CPE of both species increased with reservoir surface area. Largemouth bass *Micropterus nigricans* and crappie population characteristics demonstrated a strong relationship, with largemouth bass electrofishing catch-per-effort (*c/f*) inversely associated with crappie CPE, and directly associated to crappie growth rate and condition. These results suggest that managers should consider reservoir depth and productivity when selecting crappie species for introduction into new or renovated reservoirs, and that predator populations can be manipulated to improve growth and condition of crappie when crappie are of primary management importance.

Key words: habitat, management, morphometric, *Pomoxis*, predator-prey

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Crappie (black crappie *Pomoxis nigromaculatus* and white crappie *P. annularis*) fisheries are important across much of North America. For example, 651,000 anglers fished Mississippi waters in 2011 for more than 9 million angler days and contributed more than US$527 million to the state economy (USFWS and USCB 2011). Most (93%) of these anglers fished in freshwater, and nearly half (46%) fished for crappie, with a targeted effort of 36% of freshwater angling days directed at crappie, a close second to largemouth bass *Micropterus nigricans* (38%). This equates to more than 2.8 million angler days, and an average trip expenditure of $34 per day or $95.6 million annually in Mississippi alone. Nationwide, 7.8 million anglers spent 107 million angler days targeting crappie in 2016 (USFWS and USCB 2018).

Crappie fisheries in large reservoirs support much of the effort for crappie species (Hutt et al. 2013). Crappie are rarely recommended for stocking in ponds less than 10–15 ha (Wright and Kraft 2012), but small reservoirs (15–500 ha) can occasionally produce quality crappie fishing. Guy and Willis (1995) compared black crappie populations across 22 small impoundments, natural lakes, and large reservoirs in South Dakota and found populations to exhibit similar characteristics within system types (e.g., populations of black crappie in small impoundments showed similarities not shared with those in natural lakes or large reservoirs). However, it is not clear what specific factors contribute to quality crappie populations in small southern U.S. reservoirs. For example, water level and its effect on habitat availability has been implicated as a primary factor influencing crappie population dynamics in large reservoirs (Maceina and Stimpert 1998, Dagel and Miranda 2012), yet water levels tend to be more stable in smaller systems.

Similar to large reservoirs, small reservoirs vary in morphometry, geology, habitat, biological communities, and water quality, and these characteristics may influence crappie populations. Allen et al. (1998) found a positive relationship between black crappie density and zooplankton abundance, and suggested quality black crappie fisheries would exist in systems with elevated chlorophyll levels and surface areas greater than 100 ha. Water clarity may influence crappie dynamics, as turbidity explained 49% of crappie (black and white crappie combined) variability in an Iowa flood control reservoir (Mitzner 1991). Understanding factors that affect crappie population dynamics in small reservoirs could improve

1. E-mail: haley.bryant.m@gmail.com

management approaches because manipulation of physicochemical, biological, and morphometric factors may be feasible in these smaller systems.

In this study, we examined biotic and abiotic features that influence crappie species, growth, condition, and trap-net catch-per-effort (CPE) in 16 small reservoirs in Mississippi. Our objectives were to 1) determine influence of reservoir physicochemical characteristics on crappie populations, 2) assess fish community influence on crappie population metrics, and 3) propose management strategies to improve crappie fisheries in small reservoirs.

Methods

The 16 reservoirs ranged in surface area from 28 to 357 ha and were distributed from southern Mississippi (31.225 N) to near the Mississippi/Tennessee state line (34.794 N; Figure 1, Table 1). Thirteen reservoirs were part of the public State Lakes Program managed by the Mississippi Department of Wildlife, Fisheries & Parks (MDWFP), two were public reservoirs managed by the U.S. Forest Service (Choctaw and Davis), and one was a private reservoir that was part of a large homeowners' association (Browning Creek). Harvest regulations in these systems varied minimally, although Browning Creek was private, with restricted access. Generally, lakes managed by MDWFP were subject to a limit of 30 crappie, 10 largemouth bass, and 100 bream with no restriction on size.

Morphometric and physical habitat characteristics, including surface area (A_0), maximum depth (z_m), and relative depth (z_r), were obtained for each reservoir. Relative depth (z_r) is the

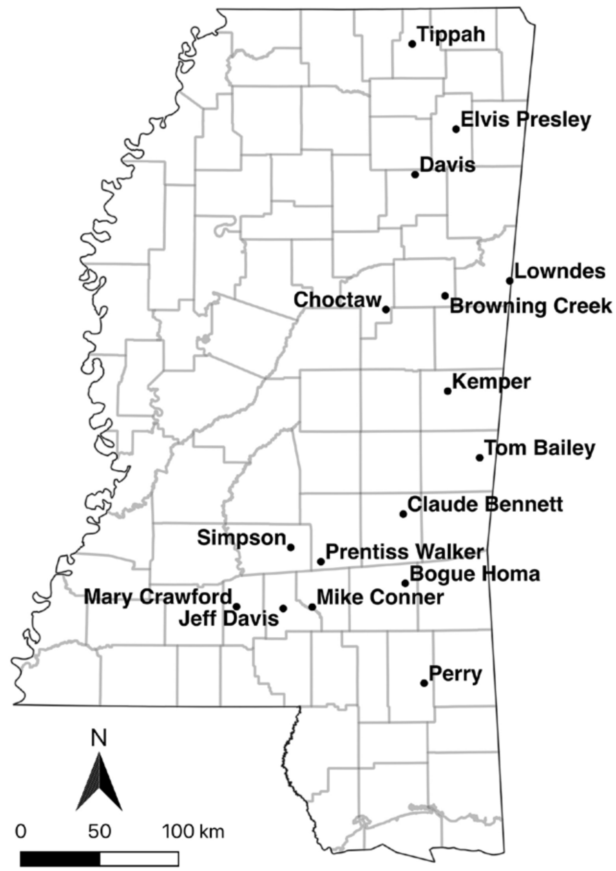

Figure 1. Map of study reservoir locations throughout the state of Mississippi.

Table 1. Water quality and lake morphometric variables for 16 study reservoirs in Mississippi. Temperature, pH, luminescent dissolved oxygen (LDO), and chlorophyll-a (Chl-a) are mean values averaged across the reservoir surface in July 2017 at 0.05-m depth.

Reservoir	A_0 (ha)	Z_m(m)	Z_r (%)	Temp. (C)	pH	LDO (mg L^{-1})	Chl-a (ug L^{-1})
Bogue Homa	357	5.49	0.26	30.67	8.61	7.12	13.85
Browning Creek	63	4.27	0.48	32.04	9.97	10.50	7.21
Choctaw	38	4.88	0.70	29.29	9.46	10.41	3.94
Claude Bennett	29	5.49	0.90	31.80	9.79	9.66	3.61
Davis	81	8.23	0.81	32.83	10.09	8.16	3.75
Elvis Presley	130	10.67	0.83	32.59	8.54	7.12	1.77
Jeff Davis	40	9.14	1.28	30.70	9.23	9.05	4.53
Kemper	241	10.97	0.63	32.70	9.00	8.07	3.47
Lowndes	61	10.06	1.14	33.28	9.52	7.40	5.37
Mary Crawford	52	4.57	0.56	32.19	10.51	11.95	4.67
Mike Conner	32	7.32	1.15	31.38	9.34	8.44	2.74
Perry	28	5.49	0.92	31.27	7.92	7.88	7.40
Prentiss Walker	33	9.14	1.41	30.59	9.88	9.45	12.01
Simpson	31	4.57	0.73	30.05	8.89	8.81	6.40
Tippah	59	9.14	1.06	31.41	9.90	9.32	2.76
Tom Bailey	74	6.40	0.66	31.36	8.10	7.62	8.71

maximum depth of a lake as a percentage of the mean diameter, calculated as:

$$z_r = \frac{50\, z_m \sqrt{\pi}}{\sqrt{A_0}}$$

Water quality characteristics were sampled, including turbidity, chlorophyll-a, pH, luminescent dissolved oxygen (LDO), and total dissolved solids. These data were collected for each reservoir in July 2017, with sampling occurring at the same time of day and under similar weather conditions. Water quality measurements were collected using a Hydrolab DS5 multiparameter datasonde (OTT HydroMet, Delft, Netherlands) attached to a flow-through system. A flow cell and peristaltic pump provided a continuous flow of water from the surface of the reservoir (0.05 m) across the sensors and back to the reservoir. This system was mounted to a boat and driven at a speed of 2–3 km h^{-1} in zigzag transects to provide representative coverage of the navigable surface. Data were recorded at 1 sec intervals and were averaged to provide a precise estimate of each parameter for each reservoir.

Fall trap netting (October and November during 2015–2017) was used to characterize species composition, size structure, and condition of crappie populations. Sampling used standard trap nets consisting of two 1 m × 2 m frames and four 76-cm hoops extended 10 m from the shoreline with a 1-m high net lead (fence). The lead of each net was attached to shore, and the net was set perpendicular to the shoreline. Nets were constructed using 1.3-cm square mesh. Net locations were chosen *in situ* with attention to shoreline slope and depth. Ideal locations consisted of a consistent slope that allowed the trap to terminate in water ≤2 m deep. Locations were distributed around the lake as evenly as possible while also proportionally representing habitat types within the lake. A minimum of 12 net-nights were completed per reservoir less than 100 ha (13 reservoirs), and 24 net-nights were used in larger systems (3 reservoirs). All crappie collected were transported to Mississippi State University where they were identified, measured (TL, mm), weighed (g), and otoliths extracted for aging. For sample sizes greater than 100, crappie were subsampled with 10 fish per 1-cm length group. Crappie populations were characterized using relative weight (W_r; Neumann and Murphy 1991) and mean length at age as the condition and growth metrics. Catch-per-effort (CPE; fish net-$night^{-1}$) and total catch served as proxies for abundance.

Fish community characteristics (species richness, catch-per-effort, size distributions, and W_r were assessed using spring (March and April) electrofishing with a boom-mounted Smith-Root 7.5 GPP electrofisher (Smith-Root Inc, Vancouver, Washington) and a target output power of 3500 W DC at 60 pps. All electrofishing occurred during daylight hours. For reservoirs less than 100 ha, 10 randomly selected sites were electrofished for 10 min. We sampled 15 sites for larger reservoirs. All fish were collected, identified, measured (TL, mm), and weighed (g) before being released. Whereas catch rate of electrofishing is measured in fish hr^{-1} and catch rate of trapnetting is measured in fish net-$night^{-1}$, we used *c/f* to indicate electrofishing catch rate to avoid confusion with trapnetting catch rate (CPE).

Canonical correspondence analysis (CCA) was employed to assess the influences of water quality and lake morphometric variables on crappie populations. CCA allows for the visual examination of ordinated variables through a triplot that shows the relative strength of interactions. CCA also acts similarly to multiple regression and reported eigenvalues may be interpreted to assess the strength of correlations. CCA does not require variables to be normally distributed. Non-metric multidimensional scaling (NMDS) ordination based on Bray-Curtis similarity index was used to visually portray the interactions of fish communities. Ordinations were performed on *Z*-score transformed data using PAST 3 (Hammer et al. 2001).

Results

Reservoirs exhibited considerable variability in crappie populations. We collected both species in 7 of 16 reservoirs, only white crappie in 4 reservoirs, and only black crappie in 5 reservoirs, (Figure 2). Mean CPE ranged from less than 0.1 (Simpson) to 41.2 (Browning Creek) fish net-$night^{-1}$. Mean relative weight was as low as 80 (Choctaw) and as high as 101 (Tippah). Mean length at age for white crappie varied considerably in fish aged 0–3 years, and much less so in fish aged 4–5 years. Black crappie mean length at age varied considerably in fish aged 0–5 (Table 2).

In CCA, Axis 1 (Figure 3, top) had an eigenvalue of 0.0613 and explained 67.1% of the variation in crappie population metrics in relation to water quality and physical habitat parameters. Axis 2 had an eigenvalue of 0.0258 and explained 28.3%. Variables correlating positively with crappie population metrics on axis 1 were temperature (0.0726), chlorophyll (0.2068), and A_0 (0.0052). Variables with a negative relationship on axis 1 were pH (-0.2778), LDO (-0.1996), z_m (-0.1556), and z_r (-0.2557). Axis 2 variables with a positive correlation were temperature (0.1098), pH (0.2512), LDO (0.2061), and A_0 (0.2472). Water quality variables negatively correlated along axis 2 were chlorophyll-a (-0.1916), z_m (-0.3223), and z_r (-0.5518). Visually, pH and LDO showed a positive relationship with black crappie CPE, whereas chlorophyll-a had a negative association. White crappie CPE was positively correlated with chlorophyll-a and temperature and negatively correlated with depth metrics. Lake depth metrics showed a positive correlation with crappie growth metrics.

Reservoirs varied considerably in physical and chemical characteristics (Table 1) and fish communities. Surface area (A_0) ranged from 28 to 357 ha, z_m ranged from 4.2 to 11.0 m, and z_r ranged from 0.26 to 1.41%. We did not sample seasonally to ascertain the annual range of water chemistry values, but variability was observed between reservoirs during July sampling. Mean surface water temperature varied from 29.3 C to 33.3 C, pH ranged from 7.92 to 10.51, and LDO (mg L^{-1}) ranged from 7.12 to 11.95. Chlorophyll-a was as low as 1.77 µg $L^{-1}$and as high as 13.85 µg L^{-1}. Claude Bennett and Jeff Davis reservoirs had the lowest species richness with only 3 species collected, while Bogue Homa had the highest at 17 species. Largemouth bass *c/f* (fish h^{-1}) varied from 16.4 (Browning Creek) to 190.7 (Tippah) (Figure 4). Largemouth bass mean W_r ranged from 69.4 (Tippah) to 96.0 (Bogue Homa). Bluegill (*Lepomis macrochirus*) *c/f* (fish h^{-1}) ranged from 11.3 (Claude Bennett) to 138.3 (Choctaw), and mean W_r ranged 79.3 (Elvis Presley) to 111.9 (Mike Conner).

Based on ordination with NMDS, crappie CPE decreased as largemouth bass *c/f* increased, although this relationship appeared to be influenced mainly by black crappie (Figure 2). Mean length at age for age-0 and age-2 crappie was also positively correlated with largemouth bass *c/f*, suggesting a predation-mediated density-dependence of growth. Age-1 crappie mean length at age did not follow the same relationship, instead displaying a weak negative

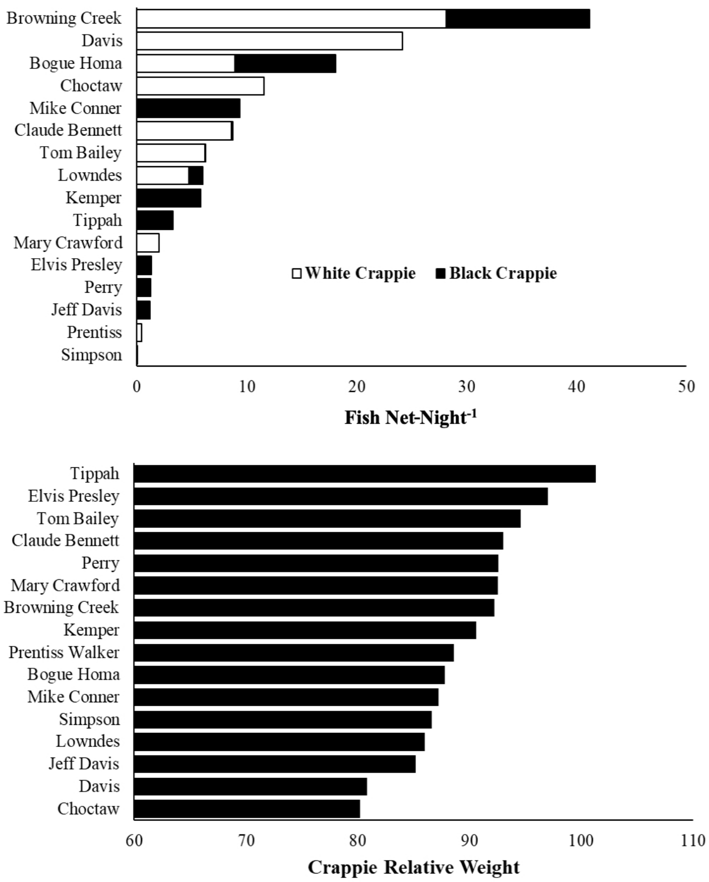

Figure 2. Crappie catch per net-night (CPE) by species (top) and mean relative weight (W_r) of both species combined (bottom) from 16 small reservoirs in Mississippi.

Table 2. Average length at age (TL; mm) for crappie species collected in all sampled lakes in Mississippi during the fall of 2015, 2016, and 2017.

Reservoir	Species	Age-0	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6
Bogue Homa	White crappie	99.4	198.9	258.9	336.2	302		
	Black crappie	87.3	163.2	227.3	271.2	299.4	229	
Browning Creek	White crappie	152.4	226.9	246.1				
	Black crappie	157	207	231.4	212			
Choctaw	White crappie	100.7	134.2	194	294.8	366		
	Black crappie							
Claude Bennett	White crappie	141.1	200.3	208.7	261.5			
	Black crappie	190						
Davis	White crappie	138.6	171	225.3	190.9	377	355	
	Black crappie							
Elvis Presley	White crappie		353	264				
	Black crappie	108.3	180.7	239.5	242.8			
Jeff Davis	White crappie							
	Black crappie	117.3	287	316				
Kemper	White crappie							
	Black crappie	82.9	186.7	250.2	296.7		354	
Lowndes	White crappie	124	208.2	256.8	334			
	Black crappie	130.6	215.5	257.4				
Mary Crawford	White crappie	144.4		238.5				
	Black crappie							
Mike Conner	White crappie							
	Black crappie		238	260				
Perry	White crappie		222.5	277.7	323.3			
	Black crappie							
Prentiss Walker	White crappie							
	Black crappie							
Simpson	White crappie	136	139	140				
	Black crappie	139.3	164	169	323			
Tippah	White crappie		153.5					
	Black crappie	149.5	204.5	293.5	320.4	341.3		
Tom Bailey	White crappie	114.3	185	239.9	282.3	305.4	312	328
	Black crappie	141.3	166.2	173.5				

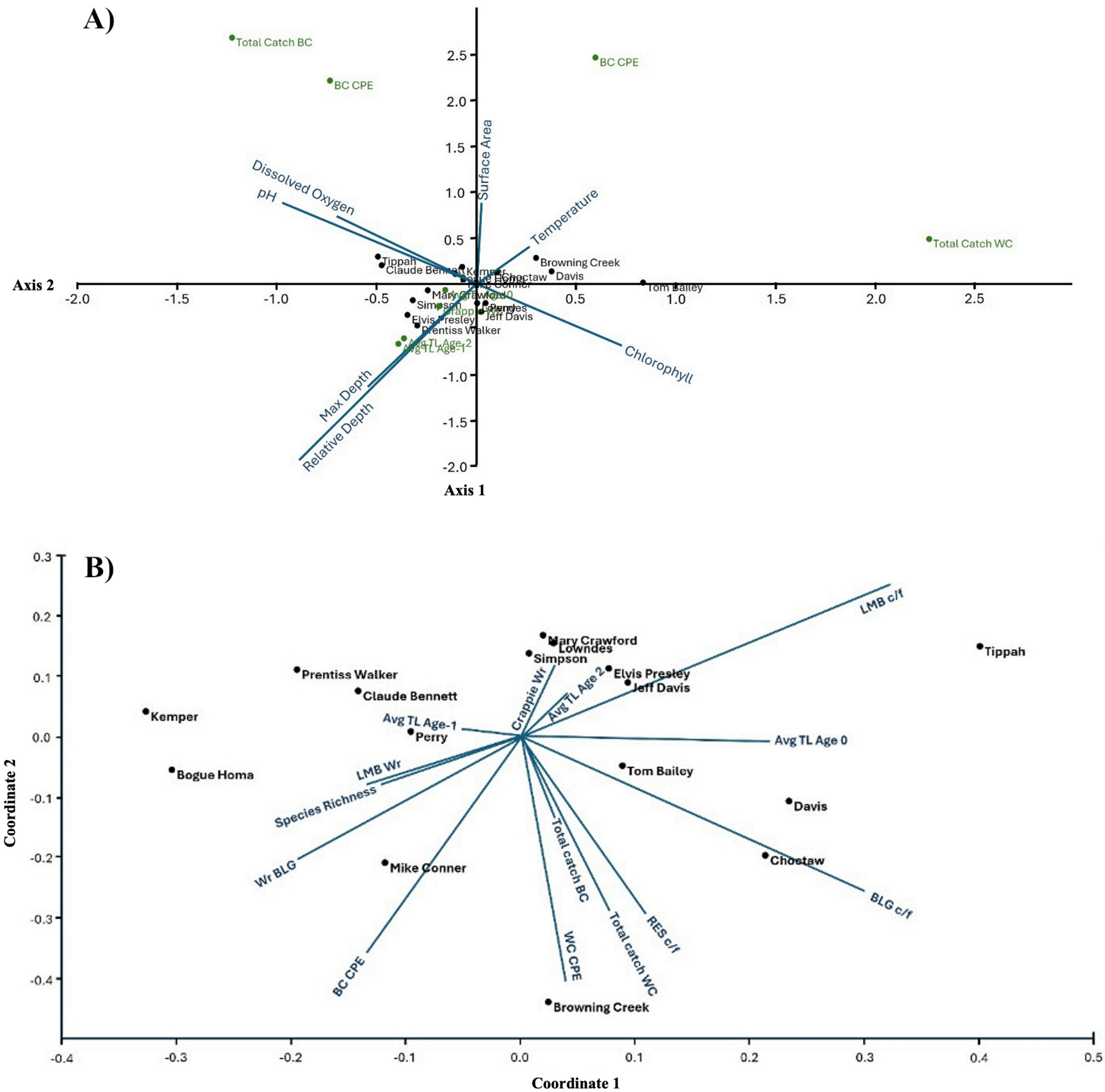

Figure 3. Ordination of reservoir variables (CCA; top) and of fish community metrics (NMDS; bottom) as compared to crappie population metrics for 16 small reservoirs in Mississippi. Variables for crappie included length at age, W_r, and catch by species [largemouth bass (LMB), bluegill (BLG) and redear sunfish (RES)]. Reservoir variables included z_m, z_r, A_0, chlorophyll-a, temperature, pH, and dissolved oxygen (LDO).

correlation with largemouth bass *c/f*. Redear sunfish *Lepomis microlophus* and bluegill *c/f* correlated positively with crappie CPE, although the effect appeared strongest between white crappie and bluegill, with no association between black crappie and bluegill *c/f* and weak relationships with redear sunfish and crappie species.

Discussion

Our examination of crappie population metrics in relation to reservoir abiotic and biotic characteristics revealed several patterns of management importance to small reservoirs. First, depth and productivity play a role in crappie species presence. Deeper lakes, which tended to have less chlorophyll-a and greater transparency, were more likely to support black crappie over white crappie, while the reverse was observed for shallower and more productive reservoirs. Ellison (1984) reported that one species usually dominates where both occur, with black crappie preferring clear water while white crappie seem better adapted to turbid waters (Hall et al. 1954, Neal 1963, Goodson 1966). Our findings also support those of Matthias et al. (2018), who noted that lakes with black crappie averaged 18% lower in chlorophyll-a concentrations than lakes with white crappie.

Black crappie appeared to associate with a higher pH than white crappie. While the physiological tolerances of several centrarchid species have been documented (e.g., largemouth bass and bluegill), there is relatively little information available on crappie (Kieffer and Cooke 2009). In contrast to our findings, Ross (2001) reported that black crappie prefer pH values between 6.0 and 7.5, while white crappie prefer slightly higher pH (6.5–8.5; Edwards et al. 1982). However, it is important to state that we assessed correlations and cannot assign causation to any given factor. It is possible that higher pH was associated with another reservoir characteristic that was driving crappie abundance. Additionally, our sampling was not seasonal, and it is possible that long-term averages of pH differ from our summer values. Further, water chemistry has been previously managed in some of these lakes by addition of crushed limestone rock. This management activity likely influenced values of water chemistry reported in this study, and could influence community dynamics of crappie populations.

Both crappie species displayed faster growth as depth increased. For both crappie species, CPE increased with reservoir surface area, while growth decreased. This density-dependent relationship between abundance and growth rate is well-established (e.g., Wright and Kraft 2012); however, the reason for increasing crappie abundance with surface area warrants discussion. We hypothesize that this relationship may be due to the decreasing ratio of littoral zone to limnetic area as reservoir size increases. Crappie are limnetic as juveniles (Layzer and Clady 1984), presumably to avoid

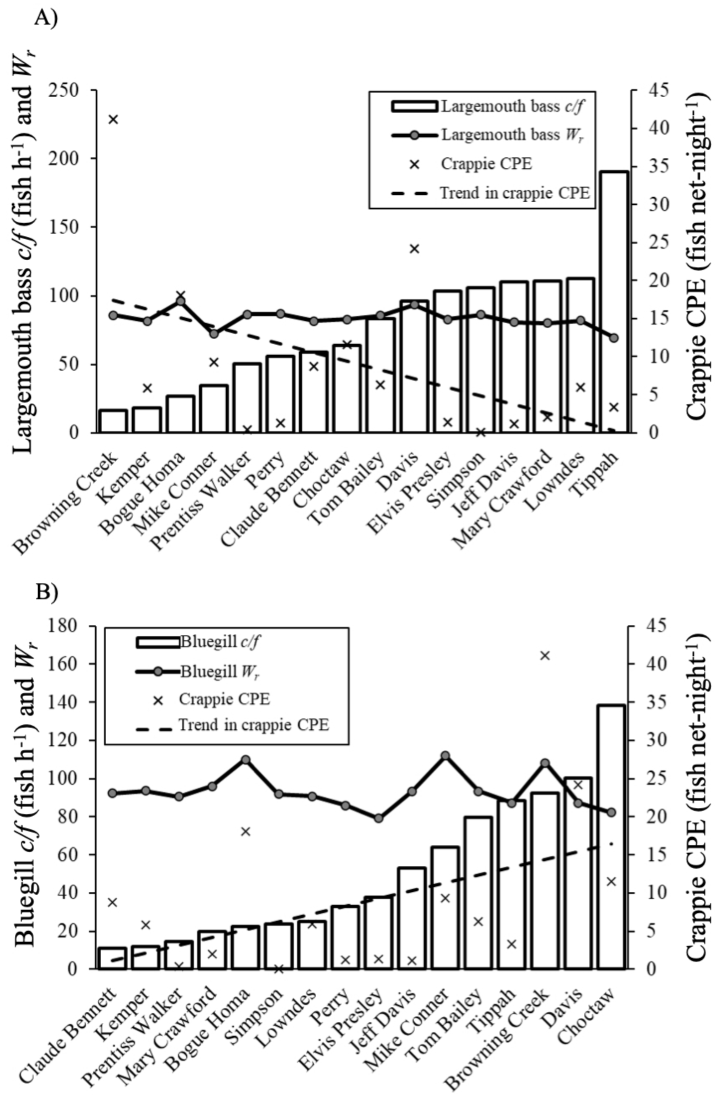

Figure 4. Relationship of crappie (both species combined) catch-per-effort (CPE) to largemouth bass (top) and bluegill (bottom) *c/f* and relative weight (W_r) for 16 small reservoirs in Mississippi.

the elevated predation risks found in the littoral zone. Smaller impoundments have relatively more littoral habitat and less separation between near-shore and offshore areas, which likely increases predation risk by largemouth bass, leading to lower crappie densities and less prey limitation for the crappie that survive (Osgood 2005, Haley and Neal 2021). This situation may be unique to small reservoirs, as larger systems offer enough habitat variability, alternative prey options, and additional predation risks that density-dependent growth issues may not occur.

The influence of largemouth bass abundance on crappie dynamics was evident in our study reservoirs. Reservoirs with high *c/f* of largemouth bass displayed lower crappie CPE but faster growing crappie with a higher W_r. Conversely, lakes with fewer but larger largemouth bass exhibited overabundant crappie populations with low *Wr*. Similar relationships were observed for other sunfish species, providing further support for this hypothesis of predator-prey regulation. Species richness followed this pattern, with greater species richness in reservoirs with lower predator abundance, adding competition with other prey species as a potential driver. This finding supports Boxrucker (1987), who reported crappie size in terms of proportional stock density (PSD) to be directly related to largemouth bass density in 11 small Oklahoma impoundments and postulated that largemouth bass drive crappie population dynamics via control of crappie abundance. In fact, establishment of a crowded largemouth bass population is a primary recommendation for crappie management in ponds (e.g., Gablehouse 1984, Boxrucker 1987, McHugh 1990, Guy and Willis 1995, McInerny and Cross 2008, Wright and Kraft 2012). In these cases, to maintain a quality crappie fishery, managers and anglers must be willing to trade quality largemouth bass fishing for a higher catch rate of smaller largemouth bass. Our research suggests that abundant largemouth bass may also improve crappie fisheries in small Southern reservoirs.

This study provides a better understanding of abiotic and biotic factors influencing crappie populations in small southern reservoirs. Management objectives should always be clearly defined before implementing management strategies, but if crappie are the primary species of interest, our research suggests potential strategies for success. First, selection of crappie species to introduce should be based on reservoir characteristics, particularly reservoir bathymetry and water transparency. In some systems, it may be possible to recontour small reservoirs to provide deeper habitat to encourage faster growth rates. Second, predator populations can be managed to promote desired crappie populations, as largemouth bass predation appears to control crappie population abundance in small reservoirs much like it does in ponds. This predator-driven dynamic allows for density-dependent differences in growth rates. When crappie management is prioritized over largemouth bass, managers can encourage a crowded predator population to improve growth rates and condition of crappie. However, these findings may not hold for other regions, so additional research in colder climates is warranted.

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