EXPLORING THE ECOLOGICAL DIFFERENCES BETWEEN BLACK CRAPPIE AND
WHITE CRAPPIE

BY

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THESIS

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Abstract

Black crappie (*Pomoxis nigromaculatus*) and white crappie (*Pomoxis annularis*) are two closely related species that support a vital catch-and-keep fishery in the central and southern United States. Management of these two species is often plagued by poor growth and unpredictable swings in recruitment, leading to undesirable size structures and population sizes. Although we have learned a great deal about these species over the last several decades, a universal solution to these problems has not been found. Oftentimes researchers and managers further complicate the issue by viewing both species as a single entity. Recent research has indicated that although these two species are closely related, they have many interspecific differences in their ecology. My thesis delves into the ecological differences between these two species with the goal of improving our ability to manage their populations. Through a multi-lake study, I analyzed how environmental variables affect recruitment and growth of black crappie and white crappie populations. I found that black crappie year-class strength was positively related to gizzard shad catch per unit effort (CPUE) and temperature, whereas white crappie year-class strength was negatively related to common carp CPUE and largemouth bass CPUE. First-year growth of both species was positively related to surface temperature; however, black crappie first-year growth was negatively related to zooplankton density whereas white crappie first-year growth was positively related to zooplankton density. A two-year telemetry study observing habitat use provided further evidence for interspecific differences in crappie ecology. My study found that black crappie were located more often in shallow, bathymetrically steep locations with sandy substrate and course woody debris, whereas white crappie were located in deeper, less steep locations. No significant difference was found between turbidity and temperature at the locations of the two species. I hypothesize that the interspecific differences I observed in both of these

studies are a function of differences in ontogenetic diet shifts. Studies have shown that while white crappie switch from invertivory to piscivory, black crappie will switch at a later age, if they switch at all. I hypothesize that the interspecific differences in habitat use and factors related to growth and recruitment are all associated with differences in diet. Further research should investigate whether these differences are related to speciation, niche partitioning, or some other stimulus. Due to complications related to tag retention during the first year of my telemetry project, I conducted a laboratory test of three attachment methods for saddle style tags. I found that inserting the anchoring wire through the dorsal musculature led to severe dermal irritation and necrosis around the tagging location. Attachment of the tag to the dorsal spines did not lead to necrosis, and the attachment method was improved by the addition of a marine-grade epoxy. None of the methods I tested led to a scenario where healthy fish maintained the tag for more than an average of ten weeks, therefore further research is required before this style of radio tagging is used.

To my mom and dad, to whom I owe everything.

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Chapter 1: Literature Review

Black crappie (*Pomoxis nigromaculatus*) and white crappie (*Pomoxis annularis*) are two members of the *Centrarchidae* family, and make up the entirety of the *Pomoxis* genus. Both species are highly sought after by recreational anglers; therefore, fisheries managers have spent decades studying various aspects of their biology and ecology. There have been three major symposiums surrounding the study of crappie, each focusing on management issues faced throughout their range.

The first symposium was held in 1982 at the 44th Midwest Fish and Wildlife Conference and titled "Crappie Management: Problems and Solutions" (Mitzner 1984). The papers published under this symposium presented the problem of small crappie, posited various explanations for the problem, and provided possible solutions. Factors affecting prey availability and feeding efficiency were thought to affect growth and survival in some systems (Ellison 1984; O'Brien et al. 1984). Stocking of prey species was tested, but led to mixed results that ultimately did not appear to lead to a long term solution to "small crappie syndrome"(Mosher 1984). Management of predators was tested in an attempt to correct density-dependent growth of crappie with success in some systems (Gablehouse 1984; Willis et al. 1984). Crappie were also found to produce more desirable fisheries in lakes with steeper morphology and a low siltation index, indicating that goals may need to be tailored to the overall potential of a lake to produce a quality crappie fishery (Hill 1984). All of these papers allude to complex interactions between environmental variables and the fish community having an effect on crappie density and growth.

The second symposium was held in 1990 at the 120th annual meeting of the American Fisheries Society and titled "Crappie Biology and Management" (Hooe 1991). As the title implies, the symposium encompassed a wide array of topics surrounding the management of

crappie. The effects of habitat alteration were studied, including the effects of aquatic macrophyte removal and the effects of warmwater discharge from a powerplant (Maceina et al. 1991; McInerny and Degan 1991). Two studies tested the effects of regulation types – specifically minimum length and bag limits - on crappie populations in an attempt to improve crappie densities and size structure, with varying results (Colvin 1991a; Webb and Ott 1991). Several papers analyzed the relationship between angling pressure and crappie populations (Colvin 1991b; Larson et al. 1991; Reed and Davies 1991) A few of these papers cautioned against reducing harvest through regulations, citing the high rate of natural mortality observed in some southern populations (Larson et al. 1991; Reed and Davies 1991). Improvements to the rearing and stocking of crappie were researched, including the evaluation of utilizing hybrid crappie (Hooe and Buck 1991; Smeltzer and Flickinger 1991). Several papers analyzed population characteristics, with most assessing various methods for measuring components of a population such as age, growth, and relative weight (Hammers and Miranda 1991; Neumann and Murphy 1991; Sweatman and Kohler 1991). Another paper consisted of a case study on changes to populations of white crappie and black crappie after changes within the lakes environment (McDonough and Buchanan 1991).

The third symposium was held in 2000 at the 130th annual American Fisheries Society meeting, and was titled "Challenges of Crappie Management Continuing into the 21st Century" (Boxrucker and Irwin 2002). This symposium built upon many of the same management issues addressed in the second symposium. A number of papers analyzed the effects of minimum length regulations on crappie populations, with few finding any positive results for anglers (Bister et al. 2002; Boxrucker 2002a; Dorr et al. 2002; Hurley and Jackson 2002; Isermann et al. 2002a). Two papers aimed to better understand the factors affecting recruitment strength and variability.

Findings included relationships between recruitment and predator-prey abundances, as well as overall hydrology of a reservoir (McKeown and Mooradian 2002; Sammons et al. 2002). Two papers assessed the effect of stocking walleye x sauger hybrids, and found that predation pressure from the stocked hybrids improved growth and size structure of both black crappie and white crappie (Boxrucker 2002b; Galinat et al. 2002). Two papers evaluated stocking success of crappie. The blacknose variant of the black crappie was found to have variable survival in Tennessee reservoirs, whereas white crappie stocked in an Arkansas reservoir were found to have very low recruitment to the fishery (Isermann et al. 2002b; Racey and Lochmann 2002). Two papers were methodological in nature and assessed the effects of electrofishing settings on crappie and the use of tag returns for calculating exploitation rates (Dolan et al. 2002; Miranda et al. 2002). A single paper tested whether turbidity levels effect the growth of black crappie and white crappie, and found that the growth of both species was unaffected (Spier and Heidinger 2002).

The topics covered in these three symposia provide an accurate representation of the body of crappie literature over the last several decades. Small size structure, slow growth, and variable recruitment all pose problems to fisheries managers trying to produce quality fisheries. Use of regulations to improve these fisheries has met minimal success in most cases (Allen and Miranda 1995; Boxrucker 1999). Many studies have strived to better understand the underlying environmental conditions that lead to poor population characteristics, but results appear to vary across regions, systems, and even years (Bunnell et al. 2006; Dockendorf and Allen 2005; Maceina and Stimpert 1998; Michaletz et al. 2012; Pope and Willis 1998). Future research should focus on collecting long-term data sets over many systems in order to fully observe regional variations in crappie population characteristics over time.

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Chapter 2: Exploring the Effects of Environmental Variables on the Recruitment and Early Growth of Black Crappie and White Crappie

Abstract

Black crappie (*Pomoxis nigromaculatus*) and white crappie (*Pomoxis annularis*) together produce a vital catch-and-keep fishery in many states, particularly in the central and southern regions of the United States. Both species of crappie are known to exhibit poor size structure and variable recruitment, problems that have plagued management biologists for decades. Because previous studies often demonstrated contradicting results, and to better understand the underlying mechanisms controlling crappie recruitment and growth, we compared black crappie and white crappie in multiple systems and incorporated a wide range of environmental variables. Five Illinois reservoirs were sampled to determine how environmental variables affect recruitment and growth of black crappie and white crappie populations. We found that black crappie year-class strength was positively associated with gizzard shad abundance and temperature, whereas white crappie year-class strength was negatively associated with common carp and largemouth bass abundance. First-year growth of both species was positively associated with temperature. First-year growth of white crappie was also positively associated with zooplankton density, whereas first-year growth of black crappie was negatively related. The differences we observed between these two species further exemplifies the need to examine crappie as two closely related yet distinct species. Our findings support the hypothesis that black crappie and white crappie differ in their foraging ecology. Variables that correlate with crappie recruitment and growth but lack an observed direct effect may be indirectly affecting crappie through their capture efficiency and the density of the prey sources of each species.

Introduction

A common issue in fisheries management is the presence of high variability in recruitment and a great deal of research has been focused on better understanding the underlying causes. Early research on recruitment led to several foundational paradigms such as Hjort's "Critical Period Hypothesis" and the "Aberrant Drift" hypothesis (Hjort 1914). These hypotheses predicted that either starvation of larvae, or the exportation of larvae from the system through currents, was responsible for the variability in recruitment. Although pioneering at the time, technical advances have indicated that recruitment variability can be controlled by a myriad of interacting variables (Houde 2008). A paradigm shift has led researchers to use multivariate methods in order to unravel the complex system behind recruitment variability (Houde 2008; Michaletz et al. 2012). A better understanding of the factors affecting recruitment variability has led to the view of recruitment as a complex interaction of abiotic and biotic variables on a multidimensional scale (Ludsin and DeVries 1997; Mitzner 1991). Metrics of growth are often closely related to recruitment as faster growing individuals increase their chance of survival by surpassing gape limitations of predators, increasing the diversity of available prey, and outcompeting smaller individuals within their cohort (Crowder et al. 1987; Graeb et al. 2004; Miller et al. 1988).

Black crappie (*Pomoxis nigromaculatus*) and white crappie (*Pomoxis annularis*) are two members of the Centrarchidae family, and make up the entirety of the *Pomoxis* genus. Crappie are sympatric across much of their range, however individual bodies of water may only contain one species. In systems where both black crappie and white crappie are present, one species will often dominate over the other (Maceina 2003). Although often managed collectively, research has highlighted many differences between the two species. White crappie are thought to be more

tolerant of turbid systems than black crappie (McInerny and Cross 2008), however the underlying mechanisms for this are not well known (Spier and Heidinger 2002). Vulnerability to sampling gear and even susceptibility to recreational angling has been shown to differ between the species (Travnichek et al. 1997; Sammons et al. 2002).

Crappie are among the most targeted sportfish in the United States, therefore biologists often concentrate on better understanding crappie ecology in order to maintain and improve their fisheries through maximizing both size and numbers of fish (Boxrucker 2002b ; U.S.F.W.S. 2011). Although progress has been made over the last 20 years there is still much we do not understand about crappie ecology (Boxrucker and Irwin 2002). Recent research has focused heavily on using recruitment as a measure of the quality of a crappie fishery (Boxrucker and Irwin 2002). Crappie recruitment is highly variable, however, as are the underlying factors controlling it (Boxrucker and Irwin 2002; Gabelhouse 1984; Pope and Willis 1998). Recruitment bottlenecks likely play a large role in crappie recruitment (Pine and Allen 2001), however the variation in factors affecting recruitment makes it hard to identify where a bottleneck occurs.

A consensus has not been reached in regards to the time at which crappie recruitment is set. Some research has found that crappie year-class strength was set by early summer of the first-year by larval abundance (Dockendorf and Allen 2005). In contrast, other research has found that larval abundance was not correlated with fall trap net catch rates for age-0 black crappie, indicating that larval production does not always control year-class strength (Pope and Willis 1998). First-year growth, and the factors controlling it, can often play an important role in setting recruitment strength (Pope et al. 2010). Faster growth and subsequent larger size can lead to a decrease in predation and an earlier shift in diet to larger invertebrates or fish, all of which can increase survival of an individual (Crowder et al. 1987; Graeb et al. 2004; Miller et al. 1988).

Several variables have been implicated as driving factors for crappie recruitment strength, with varying agreement. Hydrology, measured as flood stage or retention days has been shown to affect growth and recruitment success (Mitzner 1991; Maceina and Stimpert 1998). Others have found no correlation between recruitment and hydrology, indicating the interaction may differ by system or region (Bunnell et al. 2006). Low larval crappie densities have been attributed to turbidity in some studies, whereas others have found no correlation (Mitzner 1991; Spier and Heidinger 2002). Turbidity likely has varying effects on crappie recruitment and growth at different life stages, particularly across ontogenetic diet shifts (Wright and O'Brien 1984; O'Brien et al. 1984; Pine and Allen 2001). Various environmental conditions have been linked to strong or weak recruitment; however, results appear to differ across systems and regions. Recruitment can be affected by any variable that changes reproductive success, survival, or growth and the effect of these factors can change through different life stages. Since there are a number of possible variables affecting recruitment, determining those that play a major role in recruitment variability is extremely difficult.

Over the past two decades a great deal of research has focused on crappie recruitment, however most studies have been on one or two lakes and usually concentrate on a single environmental variable (Dockendorf and Allen 2005; Mitzner 1991; McKeown and Mooradian 2002). Due to the inherent variability of recruitment, these results may only be applicable to the system in which it was conducted. A large-scale recruitment study utilizing a number of lakes, variables, and years is needed to accurately discover the mechanisms controlling recruitment (Parkos III et al. 2010). A multivariate approach allows for a broad set of variables to be tested simultaneously, thus improving the probability of finding the main drivers of recruitment variability. Abiotic variables such as surface temperature and turbidity represent relative water

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quality, which can affect the health, growth, and feeding efficiency of young-of-year crappie. Densities of phytoplankton, zooplankton, and benthic macroinvertebrates represent prey availability for young-of-year crappie, an important factor for many fish species in regards to growth, survival, and overall recruitment.

Measures of various fish population densities represent relative effects of predators, competitors, and invasive species, all of which can affect recruitment of young-of-year crappie. Introduction of saugeyes (*Stizostedion vitreum* x *S. canadense*) has been shown to increase growth of both black crappie and white crappie by reducing the abundance of small crappie and thus decreasing intraspecific competition (Boxrucker 2002a; Galinat et al. 2002). Crappie proportional stock density was found to be inversely related to largemouth bass (*Micropterus salmoides*) proportional stock density in small impoundments in Oklahoma, further supporting the relationship between predator density and crappie growth (Boxrucker 1987). Although it is likely that black crappie and white crappie compete with other planktivores when young, the majority of research indicates that intraspecific competition has a stronger effect than interspecific competition in many systems (McInerny and Cross 2008). Both gizzard shad (*Dorosoma cepedianum*) and threadfin shad (*D. petenense*) have been found to have little effect as a competitor, despite their similar diets and relatively high densities in many Midwest systems (Gabelhouse 1984; Mosher 1984; Slipke et al. 1998). Invasive species such as common carp (*Cyprinus carpio*) are known to impact native fish populations through their effects on habitat and the food web. Common carp decrease vegetation and increase turbidity, which can be detrimental to many native species including black crappie and white crappie (Weber and Brown 2011; Egertson and Downing 2004; Michaletz et al. 2012).

Our study set out to test the relationships between a broad range of abiotic and biotic variables likely to affect year-class strength and first-year growth in both black crappie and white crappie in an effort to better understand the mechanisms controlling crappie recruitment. Year-class strength was analyzed to better understand how environmental variables relate to a strong or weak year-class, and therefore overall recruitment. First-year growth was analyzed because it is often a strong indicator of survival through the first year, and can therefore play a large role in recruitment. An understanding of how environmental variables affect the growth of black crappie and white crappie could help explain recruitment variability and lead to management practices that help stabilize recruitment. Environmental variables were chosen for our study by conducting an extensive literature review and selecting variables commonly associated with effects on crappie abundance and growth.

Methods

Year-Class Strength and First-Year Growth

Adult crappie were sampled with trap-nets and electrofishing on five lakes throughout Illinois in 2013 and were aged in order to obtain recruitment strength and first-year growth for all year classes present in each lake. These lakes spanned a wide gradient in terms of environmental variables as well as crappie population characteristics (Table 1). Trap-netting and electrofishing was conducted in the early spring when crappie move into the littoral zone to spawn, and trap-netting was conducted in the fall when they move inshore to feed (Hansen 1951).

Twenty net-nights and three hours of electrofishing effort per lake was conducted on all lakes except Lake Shelbyville, which had 40 net-nights and six hours of electrofishing due to its larger size. Trap-net locations were randomly selected within areas of the lake less than 5 feet

deep. Ten trap-nets (20 on Lake Shelbyville) were set parallel to shore with leads secured to the bank and were fished for two 24 hours sets.

Electrofishing was conducted from a boat-mounted, 240-V AC electrofishing unit with bow-mounted droppers and a single netter at the bow. Three fixed transect locations were sampled twice in the spring at the same time trap-netting was occurring. Electrofishing transects were conducted parallel to shore for 30 minutes of effort each. Samples were used to supplement trap-net catch for age and growth data.

Spring trap-netting and electrofishing was used to collect crappie for otolith extraction. Crappie were brought back to the lab and measured for total length to the nearest millimeter and weighed to the nearest gram. Otoliths were then removed, cleaned, and stored in vials to dry. Photographs of each otolith were taken by submerging the whole otolith in water and viewing under a dissection microscope equipped with a digital camera attachment. Otoliths that could not be read whole were cut using a small rotary saw, sanded, and burned. The digital camera attachment was used to image each otolith and the age of each fish was determined by two separate readers. Any discrepancies between the two readers were either resolved, or the sample was removed from analysis. Annuli were then measured using ImageJ software in order to back-calculate first-year growth of each fish (Abramoff et al. 2004). Fall trap-netting was used to calculate CPUE, as it has been found to be the most accurate measure of crappie abundance (Miranda and Boxrucker 2009).

Water Quality

A vertically integrated water sampler was used to collect a chlorophyll *a* sample monthly. Chlorophyll *a* was measured by filtering a 100mL water sample through a glass microfiber filter. Chlorophyll was extracted from the filter with acetone, and the absorbance of the decanted

solution was read with a fluorometer (Parkos III et al. 2003; Welschmeyer and Naughton 1994). Surface temperature was collected monthly with a YSI probe. Turbidity was measured monthly with a secchi disk. Both surface temperature and turbidity were measured at a fixed site near the deepest portion of the lake.

Invertebrates

Zooplankton were collected monthly at four fixed sites at each lake. At each site, a sample was taken from the littoral zone and from the pelagic zone using a 0.5 m diameter zooplankton net with 64 µm mesh (Hoxmeier et al. 2006). Samples were taken from the thermocline to the surface when thermally stratified or from the entire water column when the lake was mixed. Zooplankton samples were preserved in a 4% Lugol's solution and processed in the laboratory. Zooplankton samples were adjusted to a volume of 100 mL and 1 mL subsamples were analyzed until 200 organisms from the major groups were counted, or until 10% of the sample had been counted (Hoxmeier et al. 2006). Zooplankton were identified down to the lowest feasible taxonomic level (order or family) and enumerated.

Benthic invertebrate density was collected monthly at six sites using a modified stove pipe sampler (20-cm diameter), washing the sediment through a 250 µm mesh, and preserving the sample in a Rose Bengal and ethanol solution (Hoxmeier et al. 2009). Samples were identified down to the lowest feasible taxonomic level (order or family) and enumerated (Hoxmeier et al. 2009).

Predator/Prey Abundance

Relative abundance, measured as catch-per-unit-effort (CPUE), of non-*Pomoxis* fish species was collected using electrofishing. Electrofishing was conducted identically to the electrofishing for adult crappie, with sampling conducted once a month. To reduce the number of

variables for model building, abundance estimates were limited to a predator, a competitor, and

an invasive species. Largemouth bass was selected as the predator, as it was the most abundant

piscivorous species found in the study lakes and is known to predate upon crappie. Gizzard shad

was selected as the competitor species, as they are prolific in many Midwest reservoirs and

competitive interactions between crappie and gizzard shad has been studied with varying results

(Mosher 1984; Pope and DeVries 1994; Slipke et al. 1998). Common carp were selected as the

invasive species as they are known to be ecosystem engineers (Byers et al. 2006). Common carp

can considerably degrade watersheds by decreasing aquatic macrophytes and increasing

turbidity, two variables that have been linked to variability in crappie recruitment in previous

studies (Spier and Heidinger 2002; Weber and Brown 2011; Michaletz et al. 2012).

Analysis

A multivariate analysis was used to associate environmental variables to year-class

strength and first-year growth across the back-calculated years within each lake for both black

crappie and white crappie. Adult crappie recruitment was analyzed using a catch-curve

regression analysis (Maceina 1997). Ages obtained from otoliths were used to create a length-age

key for each lake, which was used to estimate age for all fish caught in 2013. Year-class strength

was calculated for each lake by regressing the natural log of the catch per unit effort (CPUE)-at-

age by age. The predicted values from these regressions were then used as a weighting factor to

account for sample size, including the effect of having fewer fish at older age classes (Maceina

1997). The regression was recalculated using the weighting factor, and the residuals from the

new regression were then used as a measure of relative year-class strength (Figure 1.1)(Maceina

1997). Young-of-year fish were removed from analysis, as they were not fully recruited to the

gear. First-year growth was calculated by back-calculating otolith annuli and using length-at-age 1 as a measure of first-year growth.

A list of environmental variables important to crappie ecology were gathered from previous literature. A subset of those variables that represented major abiotic and biotic factors were chosen for analysis. Variables generally fit into the categories of water quality, prey, predators, and introduced species. Environmental variables were summarized to yearly means and were then centered on their respective lake means in order to account for differences between systems.

Year-class strength and first-year growth were then modelled separately for black crappie and white crappie using the centered mean environmental variables. All possible regression models were built and Akaike's Information Criterion (AICc) corrected for small sample size was used for our selection criterion, which accounts for both model fit to the data as well as parsimony. The most parsimonious model (model with the lowest AICc value) and all models within 2 AICc units were considered supported. All environmental variables were checked for multicollinearity before their use in model building.

Results

Lakes well represented the natural variation in environmental variables commonly observed within lakes across Illinois (Table 1.1). Turbidity levels in Illinois lakes are relatively high compared to natural lakes found in the northern and southern extents of black crappie and white crappie ranges. Indices of productivity such as the densities of benthic invertebrates, chlorophyll A, and zooplankton are also relatively high compared to natural lake systems.

Common carp and gizzard shad were present in all but one of our lakes, and are known to affect native sportfish including crappie.

Recruitment strength was also variable for both species across lakes and year-classes (Figure 1.1). Overall, black crappie ages 0-6 and white crappie ages 0-7 were captured, and observed year-classes varied by lake (Table 1.2). Age-0 fish were removed from analysis, as they were not fully recruited to the gear.

Black crappie year-class strength was positively related to gizzard shad CPUE ($R^2 = 0.72$)(Table 1.3, Figure 1.2). A two-factor model with positive relationships to gizzard shad and surface temperature was also supported ($R^2 = 0.79$)(Table 1.3). First-year growth of black crappie was positively related to temperature ($R^2 = 0.23$), and negatively related to zooplankton ($R^2 = 0.16$)(Table 1.3, Figure 1.4).

White crappie year-class strength was negatively related to common carp CPUE ($R^2 = 0.18$)(Table 1.3, Figure 1.3). A two factor model with negative relationships with both common carp and largemouth bass CPUE was also supported ($R^2 = 0.38$)(Table 1.3). White crappie first-year growth was positively related to surface temperature ($R^2 = 0.20$)(Table 1.3, Figure 1.4). A two-factor model with positive relationships with temperature and zooplankton was also supported ($R^2 = 0.26$)(Table 1.3). Benthic macroinvertebrate density, chlorophyll A density, and turbidity were not present in any of the supported models for recruitment strength or growth.

Discussion

Our analysis of the effects of environmental variables and how they affect recruitment strength and first-year growth yielded varying results for the two-crappie species. Although the explanatory power for most of our models was relatively low, that is to be expected with

complex processes such as recruitment and growth. White crappie year-class strength was found

to be negatively correlated to common carp and largemouth bass abundance. Common carp are

known to be ecosystem engineers, causing degradation to macrophytes, water quality, and

benthic invertebrate communities (Byers et al. 2006; Parkos III et al. 2003; Weber and Brown

2011). Degradation of habitat from common carp may have affected white crappie reproductive

success by disturbing spawning locations or through the removal of optimal nursery habitats.

Similar detrimental effects of common carp on sportfish including white crappie were found in

Missouri reservoirs (Michaletz et al. 2012). A study of 32 highly eutrophic systems in Iowa

found white crappie CPUE was positively related to carp CPUE, while black crappie CPUE was

negatively correlated to carp CPUE (Egertson and Downing 2004). Although our results differ

from those in the Iowa study, our data does fit the author's explanation that highly eutrophic

systems with high common carp abundance shunt resources to benthivorous fish (i.e., black

crappie) whereas piscivorous fish are unable to exploit the available nutrients.

Similar to our findings, a negative correlation between white crappie year-class strength

and largemouth bass numbers was also observed in Missouri reservoirs (Michaletz et al. 2012).

Largemouth bass abundance is often a key driver in both abundance and density-dependent

growth of panfish species such as white crappie (Boxrucker 1987). Larger numbers of

piscivorous bass would lower white crappie numbers through predation with a corresponding

increase in crappie growth and size structure often observed due to density-dependent growth

and an alleviation of intraspecific competition (Boxrucker 1987; Galinat et al. 2002). Our models

indicated that increased numbers of largemouth bass coincided with decreased numbers of white

crappie, suggesting that largemouth bass predation is likely a factor influencing crappie

recruitment. The lack of a compensatory response in growth in white crappie first-year growth

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models suggests that growth is more strongly influenced by factors other than intraspecific competition in our systems.

Black crappie year-class strength demonstrated a strong positive correlation with gizzard shad CPUE and was further improved by the addition of surface temperature. Presence of gizzard shad may have released young-of-year black crappie from predation pressure, thus increasing their survival to recruitment (Storck 1986). Alternatively, it is possible that gizzard shad and black crappie year-class strength were simply correlated to one or more of the same environmental variables and that there is no causal relationship between the two species (Pope and DeVries 1994). These results suggest a strong interspecific difference between crappie species, as white crappie did not seem to gain the same benefits from the presence of gizzard shad.

The effects of gizzard shad on sportfish populations and communities are abundant in the literature, but results vary by species. Gizzard shad have been identified as decreasing growth and size structure of black crappie, with little effect on white crappie (Michaletz et al. 2012; Pope and DeVries 1994). A positive relationship between growth and abundance is a common observation in centrarchid populations. Increased growth is often associated with higher survival and therefore increased recruitment (Crowder et al. 1987; Graeb et al. 2004; Miller et al. 1988). Conversely, excessive recruitment can lead to a decrease in growth due to stunting. Gizzard shad may increase recruitment strength, while subsequently decreasing growth (Pope and DeVries 1994). Effects on growth would likely depend on whether the increase in recruitment surpasses the carrying capacity for black crappie within the system. The relatively high strength of the relationship between black crappie year-class strength and gizzard shad abundance indicates the need for continued research into the interactions between these two species.

First-year growth in black crappie correlated positively with water temperature and negatively with zooplankton abundance. The positive correlation found between water temperature and black crappie year-class strength is likely related to the relationship between water temperature and metabolic rates. Warmer water leads to increased metabolic rates in fish and therefore increased growth (Barton 2007). Increased growth subsequently leads to higher survival rates and therefore stronger recruitment (Crowder et al. 1987; Graeb et al. 2004; Miller et al. 1988). Black crappie recruitment strength may depend on increased growth in order to avoid predation or quickly reach an ontogenetic diet shift (Miller et al. 1988, Crowder et al. 1987).

The negative correlation between black crappie first-year growth and zooplankton could be a function of black crappie diet preference and the inverse relationship between benthic and pelagic energy pathways (Vadeboncoeur et al. 2002; Mitchell 1941). Juvenile black crappie diets are mainly composed of benthic invertebrates, whereas juvenile white crappie tend to feed primarily on zooplankton (Mitchell 1941). Studies on aquatic energy pathways have found an inverse relationship between pelagic and benthic productivity (Jeppesen et al. 1997, Vadeboncoeur et al. 2002). A decrease in zooplankton would suggest an increase in benthic invertebrates, the primary diet of black crappie during their juvenile stages (Mitchell 1941). An increase in benthic productivity may not have been measurable by biomass estimates, as the increase in benthic invertebrates may have been consumed by black crappie and other benthic feeding fish (Vander Zanden and Vadeboncoeur 2002).

If differences in first-year growth of crappie species are attributable to differences in benthic and pelagic productivity, we would expect to observe an opposite relationship between zooplankton and white crappie first-year growth. As expected, temperature was again the main

driver of first-year growth in white crappie, whereas a positive relationship between first-year

growth and zooplankton abundance was also present. Just as benthic productivity supported

black crappie first-year growth; pelagic productivity seems to support white crappie first-year

growth. The dichotomy between benthic and pelagic productivity and subsequent effects on

growth rates of these two closely related species may explain how these two species seemingly

compete with one another while exhibiting niche partitioning in their diets (Mitchell 1941;

Ellison 1984). Instead of competitive exclusion being the primary driver controlling dominance

of a crappie species in a system, it may simply be an effect brought on by differences in benthic

and pelagic energy pathways in the system. Further research would be needed to verify whether

this line of explanation is supported.

Diet differences between crappie species may drive previously unexplained observations

of variables differentially affecting black crappie and white crappie. White crappie are thought to

tolerate turbid water better than black crappie, however controlled studies have shown vastly

differing results (Andree and Wahl 2019; Spier and Heidinger 2002; Ellison 1984; Mitzner

1991). High turbidity often indicates that a system is in a pelagic-dominated stable state that

would favor the diet preferences of white crappie over black crappie (Vander Zanden and

Vadeboncoeur 2002; Mitchell 1941). Instead of a direct effect of turbidity on crappie, it is likely

that turbidity is correlated to high pelagic productivity, which in turn supports white crappie over

black crappie. Hydrology, interspecific interactions, and other environmental variables

implicated in variability of crappie recruitment and growth may be acting through their effects on

each species' preferred prey resources (DeVries et al. 2009). White crappie tend to dominate

most reservoir systems in the Midwest, whereas black crappie tend to dominate in natural lakes.

Midwestern reservoirs are often plagued by high nutrient inputs from agriculture, and thus

display higher pelagic productivity. Natural lakes tend to display higher benthic productivity due to increased light penetration and thus higher benthic algal and macrophyte growth. Benthic and pelagic stable states in reservoir and natural lake systems may explain crappie dominance, both regionally and in a given system. Further research into crappie recruitment and growth should delve deeper into the differences between black crappie and white crappie ecology, particularly in the first year of life. A better understanding of how environmental variables affect young-of-year crappie and how those effects differ between black crappie and white crappie will improve the ability of biologists to make management decisions regarding habitat improvement, changes in water quality, or selecting the appropriate species of crappie for stocking. Further research should also take into account that there are likely to be numerous factors that play a role in both recruitment and growth of black crappie and white crappie and that these factors will not only differ by species but may differ by region, by system, or even annually within a system.

Tables and Figures

Table 2.1. Mean measures of environmental variables for five lakes in central Illinois. Variables were centered on these lake means in order to calculate intra-lake variation by year. Fish species include white crappie (WHC), black crappie (BLC), largemouth bass (LMB), common carp (CAP), and gizzard shad (GZS).

Variable	Lake Means				
	Forbes	Lincoln	Paradise	Pierce	Shelbyville
Species Present	WHC	BLC	WHC	Both	Both
Surface Area (ha)	225.99	56.9	57.6	61.2	4492
Mean Benthos (# per m^2)	19914 (8854)	10273 (1764)	8369 (1904)	10133 (3068)	3185 (868)
Mean Chlorophyll A (ug/L)	22.90 (2.13)	19.12 (5.54)	63.54 (5.18)	25.72 (2.64)	18.69 (2.16)
Mean Macro Zoop (#/L)	283 (82)	148 (34)	226 (47)	112 (49)	157 (27)
Mean Secchi (m)	0.71 (0.02)	2.17 (0.35)	0.47 (0.01)	1.07 (0.17)	1.02 (0.05)
Mean Temp (C)	24.63 (0.63)	23.92 (1.10)	25.02 (1.04)	21.87 (0.47)	23.26 (0.50)
Mean LMB (# per hour)	31 (1)	55 (8)	22 (5)	48 (12)	47 (11)
Mean CAP (# per hour)	4 (1)	0 (-)	10 (2)	1 (1)	8 (3)
Mean GZS (# per hour)	20 (5)	0 (-)	132 (29)	134 (48)	205 (53)

Table 2.2. Mean length-at-age, standard error, and sample size (in parentheses) of white crappie and black crappie caught in 2013 from five Illinois reservoirs. Some ages were excluded from analysis due to small sample size.

Lake	Species	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
Forbes	WHC	172 ± 5.4 (19)	192 ± 3.9 (7)	203 ± 3.3 (44)	218 ± 4.0 (10)	280 ± 10.1 (7)	350 ± 6.0 (2)	-	-
Lincoln Trail	BLC	-	240 ± 14.3 (3)	268 ± 3.1 (6)	297 ± - (1)	319 ± - (1)		-	-
Paradise	WHC	153 ± 1.3 (4)	159 ± 9.0 (2)	177 ± 0.9 (45)	218 ± 20.7 (7)	211 ± 48.8 (3)	247 ± 40.2 (3)	-	226 ± 33.3 (3)
Pierce	WHC	-	200 ± 12.6 (4)	267 ± 3.8 (6)	-	-	-	-	-
Pierce	BLC	-	185 ± 1.9 (58)	234 ± 12.3 (10)	265 ± 8.9 (8)	-	298 ± - (1)	-	-
Shelbyville	WHC	171 ± 2.5 (26)	219 ± 6.4 (13)	257 ± 7.1 (9)	268 ± - (1)	-	-	-	-
Shelbyville	BLC	158 ± 6.1 (19)	201 ± 19.2 (5)	219 ± 2.8 (37)	232 ± 6.6 (12)	287 ± - (1)	227 ± - (1)	-	-

Table 2.3. Regression models selected using AICc explaining variation in year-class strength and first-year growth in white crappie (WHC) and black crappie (BLC) from reservoirs in central Illinois. Parentheses indicate whether the relationship is positive (+) or negative (-).

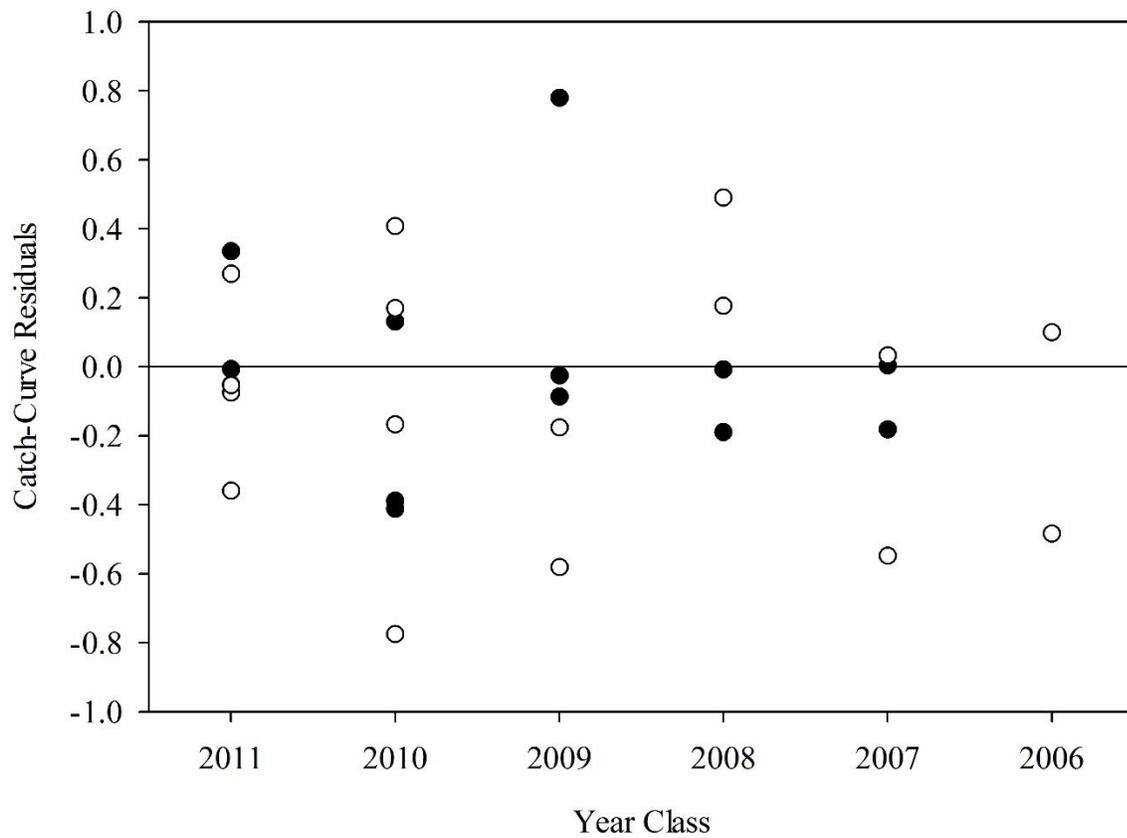| Explanatory Variables	R^2	ΔAICc
Year-Class Strength		
Black Crappie		
Gizzard Shad(+)	0.74	-
Gizzard Shad(+), Temperature (+)	0.79	1.67
White Crappie		
Common Carp(-), Largemouth Bass(-)	0.38	-
Common Carp(-)	0.18	0.83
First-Year Growth		
Black Crappie		
Temperature(+)	0.23	-
Zooplankton(-)	0.16	1.32
White Crappie		
Temperature(+)	0.20	-
Temperature(+), Zooplankton(+)	0.26	1.87

Figure 2.1. Relative year-class strength measured as the residuals from the regression of natural log transformed catch-per-effort by age of black crappie (black circles) and white crappie (open circles) by year-class for 5 Illinois lakes.
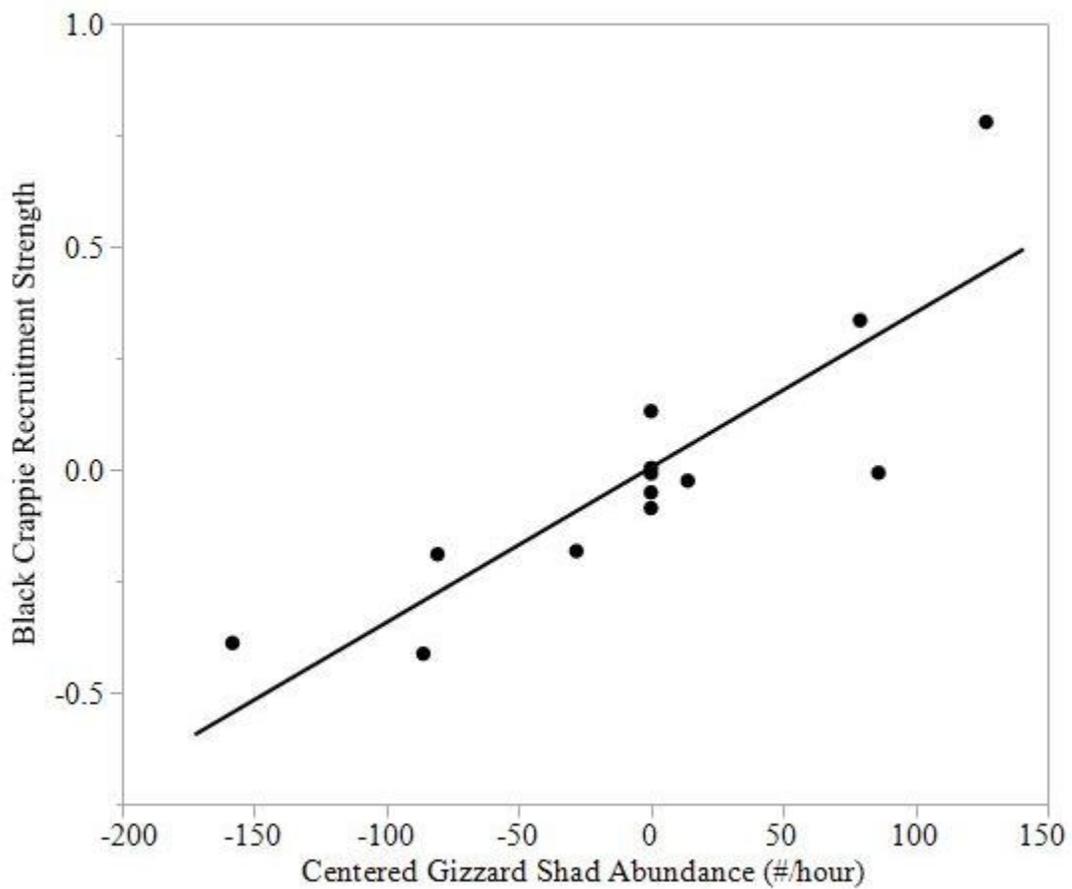
Figure 2.2. Linear regression of the residuals from the regression of natural log transformed catch-per-effort-by-age against age for black crappie from three Illinois reservoirs, plotted against mean-centered gizzard shad abundance.

Figure 2.3. Linear regression of the residuals from the regression of natural log transformed catch-per-effort-by-age against age for white crappie from four Illinois reservoirs, plotted against mean-centered common carp abundance.

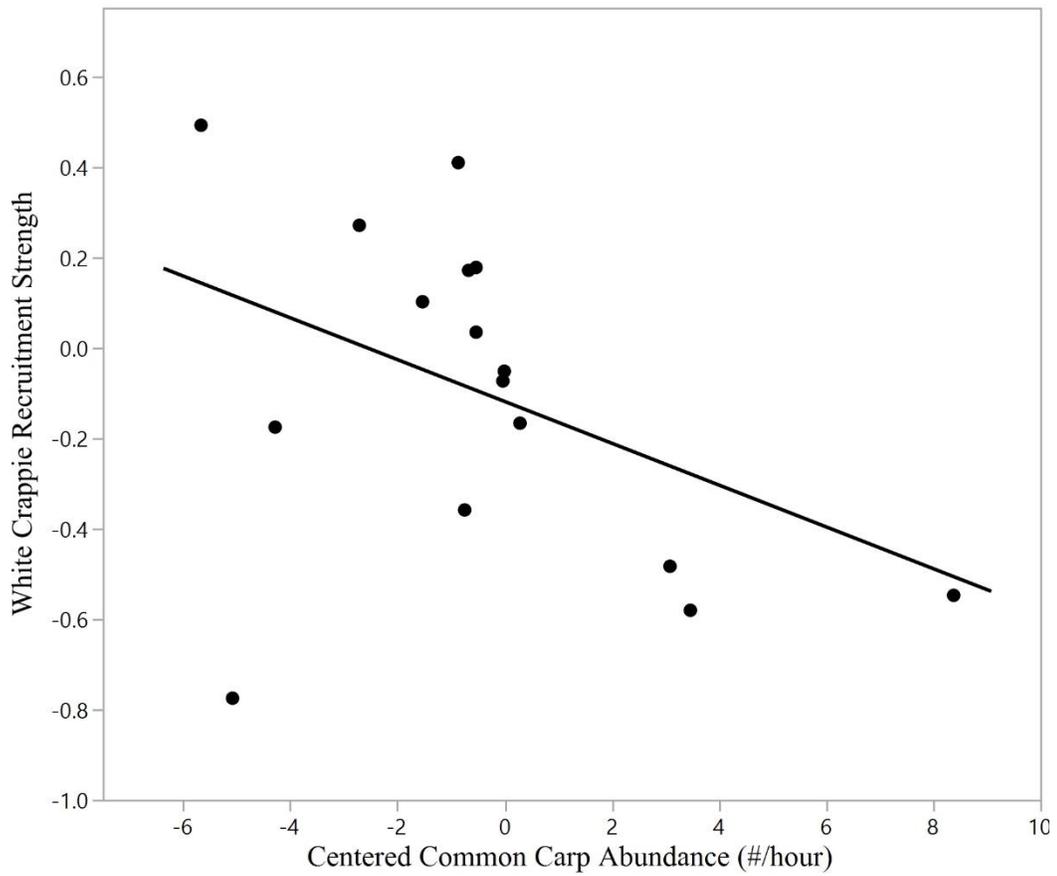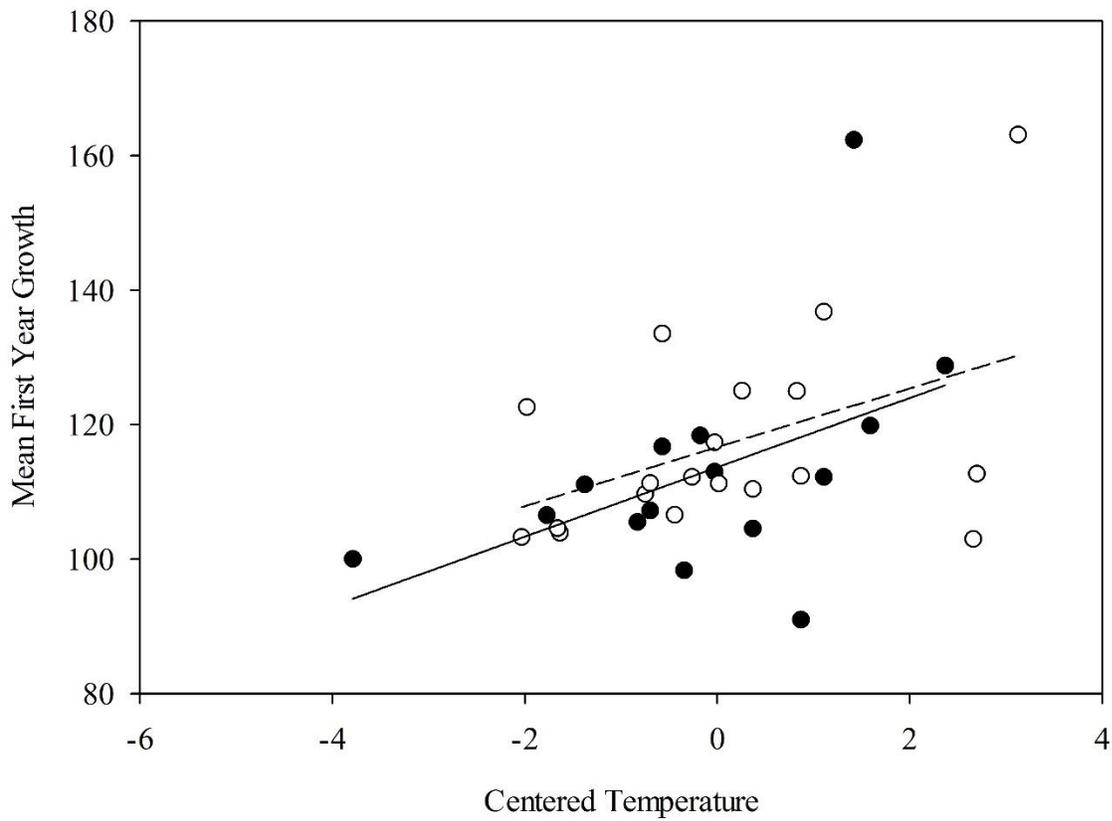Figure 2.4. Linear regressions of mean first-year growth of black crappie (black circles, solid line) and white crappie (white circles, dashed line) from five Illinois reservoirs plotted against mean-centered average yearly surface temperature.

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Chapter 3: Differences in Habitat Use of Black Crappie and White Crappie

Abstract

Despite their importance to many fisheries throughout North America the ecology of black crappie and white crappie is not fully understood, particularly when it comes to differences between the two closely related species. Interspecific differences in ecology and habitat use can have critical management implications, particularly when two species are managed together as is often the case with crappie. We monitored habitat use of adult black crappie and white crappie in Lake Mattoon, IL using radio telemetry. Habitat variables including depth, slope, substrate, and structure presence (wood, docks, vegetation) were collected everywhere a fish was located. Black crappie were located more often in shallower, steeper locations with sandy substrate and course woody debris, whereas white crappie were located in deeper, less steep locations. No significant difference was found between turbidity and temperature at the locations of the two species. Previous studies indicate that black crappie are often more invertivorous, whereas white crappie are often more piscivorous. Interspecific differences in habitat in our study may be explained by these differences in diet, and suggests niche partitioning between the two closely related species.

Introduction

Use of biotelemetry has increased dramatically in the last two decades (Cooke et al. 2004). Advances in technologies have provided researchers the ability to study fish in ways they had never been able to in the past. Among these improvements is the development of smaller and lighter telemetry tags. These tags are able to fit on species that were previously too small to tag, thus increasing our ability to study new species. Advances in GPS and side-scan sonar technology have aided in this endeavor, allowing habitat metrics to be measured more quickly and accurately than ever before (Goclowski et al. 2013). The integration of multiple forms of technology is proving to be synergistic, allowing for the collection of data sets that were unattainable a mere decade ago. The combination of novel side-scan sonar technology, GIS programming, GPS, and longer-lasting telemetry tags allows for a more precise analysis of habitat selection of fish than has previously been possible (Goclowski et al. 2013; Kaeser and Litts 2010).

As two of the most sought after game fish in the United States, black crappie and white crappie are an integral component of many recreational fisheries (U.S.F.W.S. 2011). The high degree of angling pressure on these fish makes understanding their environmental needs, such as habitat preference, imperative in order to best manage their populations. Black crappie and white crappie differ in many aspects of their life histories, yet few studies have examined the possible differences in their habitat use in sympatric systems. Previous telemetry studies on crappie have been conducted on natural lakes with relatively shallow, homogenous basins and no thermocline (Guy et al. 1992; Guy et al. 1994) Extrapolation of those results to larger systems commonly found in the Midwest may not be appropriate. A previous study in Midwest reservoirs only examined white crappie and was focused on movement, not habitat use (Markham et al. 1991). A

large reservoir in the South has also been assessed for crappie movements but the climate, and therefore many of the environmental factors, are much different than systems in the Midwest (Michaletz et al. 2012). Most crappie telemetry research was completed 15-20 years ago (Markham et al. 1991; Guy et al. 1992; Guy et al. 1994), and advances in technologies allows for more accurate collection of data on position, depth, lake morphometry, as well as habitat mapping. In this study, we examined the differences in habitat use between black crappie and white crappie in a sympatric system. By attaching radio telemetry tags to individuals of both species and monitoring their spring habitat use over two years, we examined differences in habitat use between the two species in finer detail than has previously been conducted.

Methods

Study Site

Lake Mattoon is a medium sized reservoir (425 ha) located in central Illinois and was chosen as the model reservoir for this study due to a wide range of abiotic and biotic variables such as depth, water clarity, and a heterogeneity of habitats that are commonly observed in Midwest impoundments. The main basin of Lake Mattoon has varying degrees of bathymetric slope and depth, as well as numerous bays and backwater areas. The lake has an average depth of 3.2 m with a maximum depth of 10 m located in the south end. The habitat types in Lake Mattoon include an array of sediments from silt to gravel, coarse woody debris (CWD), vegetation, and man-made structures (docks, seawalls, etc.). The lake has good populations of both black crappie and white crappie, confirming that appropriate habitat is available for both species.

Due to the importance of obtaining individuals with pure genetics for both species, individuals were obtained from monospecific crappie lakes. Individuals were captured using modified fyke nets the fall prior to tracking to ensure that fish would be available to release before spring staging. Fish were transported and overwintered in holding ponds at the Sam Parr Biological Station (Kinmundy, IL). Saddle style radio transmitters (Series F2200) from Advanced Telemetry Systems (ATS) were externally attached to the anterior portion of the dorsal fin base. The tags weighed 4.5 grams, therefore only fish over 225 grams were tagged for the study to ensure tags were less than 2% of individual body weight (Winter 1977). The saddle style tag is designed to evenly distribute weight on either side of the fish. Each tag emitted a unique frequency allowing for identification of individual fish. The tags had a maximum range of approximately half a kilometer and a battery life of 381 days. Forty fish were tagged in 2014 (20 white crappie, 20 black crappie), and 30 fish were tagged in 2015 (15 white crappie, 15 black crappie).

Crappie were anesthetized before attachment using a standard solution of Aqui-S. Once fish were anesthetized, they were placed on a surgical table in which a plastic-covered foam trough held the fish in place while water was gently circulated across the gills via a submerged pump and plastic hose placed 1-2 inches into the mouth. In 2014 saddle tags were attached using two 16-gauge needles and a single piece of 24-gauge galvanized steel wire. All tools and supplies were sterilized with ethyl alcohol before and between each individual surgery. The two needles were passed between the pterygiophores of approximately the 3rd and 5th dorsal spines, approximately 1 cm down from the top of the dorsal musculature. A piece of 24-gauge wire, doubled over into a U shape, was first fed through the two center pre-drilled holes on the battery

side of the saddle tag. Each end of the wire was then fed through the pointed end of its corresponding needle. The needles were then removed, leaving the ends of the wire exposed on the other side of the fish. The ends of the wire were then fed through the corresponding pre-drilled holes in the chip side of the transmitter. The two wire ends were then secured with a pair of clamping pliers and twisted until the wire was tightly securing the tag to the body of the individual. The twisted wire was then bent back to prevent fouling by vegetation. The entire tagging process took no more than three minutes. Once surgery was complete, individuals were returned to a tank with fresh aerated water and monitored for recovery. Tagging in the second year was modified in an attempt to reduce tag loss and increase the duration of successful tracking. Tags were secured to the 3rd and 5th dorsal spine, approximately 5 mm above the dorsal musculature. A binary epoxy (Loctite® Epoxy Marine) was applied between the two tag halves to further secure the tag to the dorsal spines. All fish were monitored for several days for mortality or tag loss before they were released into the lake.

Field Telemetry and Habitat Measurements

Fish were transported and released into Lake Mattoon during the second week in April in both years. Two release locations were chosen, each roughly centered on the upper and lower basins of the lake. Half of each species were released at each site, with the intent to initially distribute both fish and species equally across the entire lake. Fish were released over deep water to encourage dispersal, as well as to hinder any bias in habitat use associated with release site. The fish were allowed a one-week acclimation period before tracking began.

Tracking was conducted over a two day period once per week. Each day a transect around the entire northern or southern basin was conducted by making a complete loop around the entire basin, including backwater areas. The transect was centered between the shoreline and

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middle of the lake to ensure maximum coverage. Once fish in the immediate area of the boat launch were located, tracking proceeded around the lake while cycling frequencies at a 4-second rate, or 15 frequencies per minute. Boat speeds were kept slow enough to allow a full cycle of frequencies to be scanned approximately every 100 meters. A fish was initially located when the signal was equal in all directions via a bidirectional loop antenna (Butler and Wahl 2010). To increase positional accuracy a whip antenna was then used to find the position with the greatest signal strength (Butler and Wahl 2010). Tracking continued on a weekly basis until each fish was located at the same location three consecutive weeks, and therefore had either died or shed their tag.

A GPS location was recorded, along with total depth (m) and surface temperature (°C). Turbidity was measured to the nearest tenth of a meter using a secchi disk. Substrate composition was obtained using a ponar sampler, and was measured in millimeters and later converted to the Wentworth scale. Vegetation was quantified in littoral areas as distance from shore (m), and relative percent density of the growth. Lake Mattoon is devoid of vegetation except for the occasional littoral stand of water willow (*Justicia americana*); therefore a method using visual quantification was sufficient. CWD complexity was scored using a method designed by Mallory et al. (2000) and modified by Wagner (2007), in which the overall area (m^2) of the structure as well as complexity of branching was visually quantified.

A Humminbird 998C side-scan unit was used to record bathymetric data concurrent with tracking. Data was transferred to a computer and converted using SonarTRX (Version16.1; Leraand Engineering Inc.). The longitude (X) and latitude (Y) coordinate data from the side-scan GPS, as well as the depth data from the side-scan transducer (Z) (hereby XYZ) were extracted from the down-scan channel of the data set. The XYZ data were then transferred to ArcMap and

entered using the Input XYZ tool. A polygon of the lake was hand digitized from an aerial photograph to represent the area of the lake and a second version was created as a polyline to represent the shoreline, and was given a Z value of zero. The lake polygon, shore polyline, and the XYZ data were all input into the Create TIN tool and a TIN model was created. The TIN model was used to locate erroneous data points, which were removed and the TIN model recalculated. The TIN model was then converted to a raster file, which was subsequently used as an input into the Slope tool to calculate the bathymetric slope using nearest neighbor calculations from the depth raster file. All fish locations were then superimposed onto the slope raster, and a 10 m radius buffer created around each fish location. The Zonal Statistics tool was used to calculate the average slope within a 10 m radius of each fish location. The averaged slope calculation was then assigned as the slope at each fish location. A 10 m radius was used for the approximate location error rate, and was calculated by measuring positions taken on tags that had become stationary during the study.

Movement was measured as the minimum distance through water between each consecutive location. Home range was determined by creating a minimum convex polygon encompassing all locations for each fish and then measuring the area of that shape that encompassed water.

Analysis

A protected multivariate analysis of variance (MANOVA) was used to decrease the risk of committing a type 1 error when running multiple ANOVAs (Beauchamp et al. 2007; Scheiner 1993). Habitat measurements were summarized by individual fish for both sampling years. Depth, surface temperature, turbidity, and slope were summarized as means for each individual.

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Vegetation, CWD use, dock use, and sediment types were all summarized to a percentage of total locations in which a habitat feature was present for each fish. Each parameter was tested for normality (Shapiro-Wilk) and homogeneity of variance. CWD use, vegetation, dock use, and sediment types all failed to meet assumptions for MANOVA. A logit percent transformation was successful in normalizing CWD data. Vegetation, dock use, and sediment type were not able to be normalized due to the high number of zeros in each dataset. Sediment types from the Wentworth scale were further summarized into four main groups. Fine sediment included sediments up to 63 µm, and represented silt and clay. Sand included sediments from 64 µm up to 2 mm, and represented the entire family of sand classes in the Wentworth scale. Gravel included sediments from 2 mm up to 256 mm, and represented the entire family of gravel in the Wentworth scale. As there were no natural sediments larger than 256 mm the final category riprap represents areas in which broken concrete was placed for erosion control. The new sediment classifications were reanalyzed for statistical assumptions. Fine and sand sediment types were found to meet assumptions. Transformations were attempted on gravel and riprap; however, the datasets still contained too many zeros to be normalized and were therefore removed from further analysis. A correlation matrix was used to ensure parameters were not correlated. A protected MANOVA was then used with year as a random blocking factor to test for overall significance between species ($\alpha = 0.05$). If the protected MANOVA was found to be significant, univariate analysis of variance (ANOVA) with year as a random block was used to test for significant differences of individual parameters between species ($\alpha = 0.05$). Weekly movement and home range was analyzed between species using a Wilcoxon signed-rank test. All analyses were conducted using SAS (Statistical Analysis System, Version 9.3; and JMP, Version 12. SAS Institute, Cary, NC).

Results

Black crappie (N=20) and white crappie (N=20) were tagged and released into Lake

Mattoon in 2014, whereas 15 of each species were released in 2015. Of the 70 fish released over

both years, 63 fish (27 white crappie, 36 black crappie) produced valid data points (Figure 2.1).

The remaining 7 fish were either never located, or were found to have either died or shed their

tags during the beginning weeks of the experiment. Individual fish produced anywhere from 1-17

valid positions (mean 5). The experiment was only conducted during the spring and summer of

2014 and 2015 due to an issue with tag retention and mortality related to tag design and

attachment (Chapter 3). Fish appeared to disperse upon release, as individuals were located

throughout the reservoir.

Movement ranged from individuals residing in a small area for several weeks at a time, to

traversing the entire length of the lake in a single week. Black crappie moved a median of 507

meters per week, while white crappie moved a median of 540 meters per week. There was not a

statistically significant difference in movement rates by species ($Z = 0.92$, $P = 0.36$; Figure 2.2).

The median home range for black crappie was 12.65 ha, while the home range of white crappie

was 30.65 ha. There was not a statistically significant difference in home range size by species

($Z = 0.91$, $P = 0.36$).

A significant overall difference between white crappie and black crappie habitat metrics

was found (protected MANOVA: $F_{6, 55} = 3.84$, $P = 0.003$). Year was not found to be

significant, and was therefore removed from the model. A significant MANOVA result allowed

univariate tests to be conducted on each habitat metric (Table 2.1; Figure 2.3). White crappie

frequented deeper water than black crappie ($F_{1, 60} = 9.99$, $P = 0.003$), whereas black crappie

were more often associated with CWD ($F_{1,60} = 6.19$, $P = 0.01$). Black crappie were also found

to inhabit areas with greater bathymetric slope than white crappie ($F1,60 = 6.33$, $P = 0.01$). For sediments, white crappie were found more often in areas with fine sediment ($F1, 60 = 7.44$, $P = 0.008$), while black crappie had a marginally higher occurrence in sandy areas ($F1, 60 = 3.35$, $P = 0.07$). There were no significant differences between species in relation to selection of temperature or turbidity ($P > 0.05$).

Discussion

An understanding of habitat use is important when trying to better understand the biology of two closely related species. Although white crappie and black crappie are indeed closely related, we found that their use of available habitat can be quite different. Black crappie were located in steep, littoral areas with sand, particularly in areas that also contained CWD. White crappie were located in deeper areas with slightly less slope than black crappie, and utilized CWD less often. These results support previous research highlighting various differences between these two species including diet, growth, recruitment, and physiology (Metcalf et al. 1972; Michaletz et al. 2012; Mitchel 1941; Neal 1963).

A major difference that has been observed between black crappie and white crappie is diet. Black crappie are known to be more invertivorous than white crappie, particularly in the spring (Pelham et al. 2001) and as they mature (Mitchell 1941; Ellison 1984). The littoral zone, which often contains CWD and vegetation, typically has a higher density and diversity of aquatic invertebrates than offshore habitats. Littoral areas are more productive due to a combination of allochthonous nutrient inputs and increased sunlight, which provides warmer water and increased photosynthetic activity. Presence of macrophytes and CWD leads to an increase in density and diversity of aquatic invertebrates by providing increased surface area, various types of prey, and

refuge from predators (Harmon et al. 1986; Gregg and Rose 1985). The presence of black crappie in littoral areas with CWD is likely related to the high invertebrate forage densities that these habitats provide.

White crappie tend to switch to piscivory early and fish become a large percentage of their diet as adults (Mitchell 1941; Ellison 1984). Forage fish such as young-of-year gizzard shad can typically be found in schools on littoral drop-offs (Netsch et al. 1971). The presence of white crappie in deeper water than black crappie is likely a function of white crappie feeding on fish over littoral drop-offs. Black crappie have little reason to travel into deeper waters as their prey is concentrated in the littoral zone. White crappie, however, may find it necessary to move to deeper water in search of forage fish. Differences in diet and habitat use may have resulted from niche partitioning between two closely related species (Mittelbach and Persson 1998). In order to minimize competition, the two species diverged their ontogenetic diet shifts with black crappie maintaining an invertivorous diet, and white crappie quickly switching to a piscivorous diet.

Although we found differences in average depth utilized by the two species, few individuals of either species frequented areas deeper than 5 m. This is likely related to the presence of an oxycline around this depth, which restricted both species and much of their prey to this depth strata. Individuals that were located in deeper water were likely suspended at or above 12 feet; however, we were not able to confirm this hypothesis as the tags that were used did not measure depth. The use of CWD by both species is well known, and although the average presence of CWD at a single location was only 32% for black crappie, and 19% for white crappie, a total of 75% of black crappie individuals and 44% of white crappie individuals were located near CWD at some point during the experiment. Furthermore, these should be considered

conservative measurements, as it is possible that a portion of locations may have contained CWD that was not detected visually or via sonar.

Basin slope has been shown to affect population dynamics of crappie (Hill 1984). Slope proved to be an important factor in heterospecific habitat use as well. Although the calculations were relatively coarse in resolution (approximately 10 m) due to methodological constraints, black crappie were found to be related to steeper sloped areas than white crappie. Steeper locations in Lake Mattoon often times contained sandy substrate, which black crappie were found to utilize more often. Some of the steepest areas of the lake were fortified using broken concrete (riprap). Although riprap had to be excluded from analysis due to normality violations (in part due to the rarity of riprap in the system), it is possible that riprap provided increased invertebrate forage which drew black crappie to steep areas. Both species utilized steeper areas than the lake average, as both species appeared to utilize littoral drop-offs.

The use of fish from monospecific lakes minimized the possibility of hybridization; however, there is the possibility that translocating adult fish to a new waterbody may have affected their behavior. Genetic purity was critical to our study design, therefore the movement of fish from outside waterbodies was deemed necessary. Both species were introduced into a new waterbody; therefore, any differences in behavior related to movement would still represent interspecific differences to their environment. Further research comparing both species simultaneously will have to consider this trade-off between genetic purity and the effects of translocating fish.

Crappie are known to have increased movement during crepuscular and nocturnal periods, and are least active during daylight hours (Guy et al. 1992, Markham et al. 1991). All of our tracking was conducted during daylight hours; therefore, our data was likely gathered during

a period of low activity. Habitat use of crappie could differ when observed at night, and should be considered for future research. There was not a statistically significant difference in weekly movement rates of the two species. Weekly movement is a fairly course measure, and we suggest those interested in movement rates utilize fixed-station telemetry systems that allow for sub-hour monitoring of fish activity.

Home range did not statistically differ between species; however, the median home range of white crappie was over double that of black crappie. Feeding on gizzard shad in the limnetic zone may lead to an increased home range size in white crappie due to variability in location of prey. Conversely, black crappie orienting to woody structure would have smaller home range. Future studies looking into home range should utilize fixed-station systems that allow for the collection of large numbers of locations.

Our study highlights differences in habitat use between black crappie and white crappie in a Midwest reservoir. Crappie are often managed as a single taxon, however our study indicates that the two species utilize different habitat types. Lake managers should consider which species is prevalent in their system, and manage accordingly. Our study suggests not only the types of habitat improvements that could improve crappie populations, but also where to conduct them. CWD additions would appear to benefit both species, though black crappie would likely receive greater benefit due to their higher usage. CWD additions would benefit both crappie species the most when added to areas in the 2.5-3.5 meter depths. If construction of a manmade lake was being considered, the presence of high slope areas would appear to attract crappie, and has already been shown to improve both numbers and size (Hill 1984). Further research should be conducted to determine differences in black crappie and white crappie habitat use across

temporal scales, both diel and seasonal, to further expand on the interspecific differences that we

found during the spring and early summer.

Table and Figures

Table 3.1. Means, standard errors, and P-values from protected ANOVAs for habitat metrics of

radio-tagged white crappie and black crappie in Lake Mattoon during spring of 2014 and 2015.

	White Crappie	Black Crappie	
Parameter	LSMean (SE)	LSMean (SE)	P-value
Depth (m)	3.08 (0.29)	2.44 (0.28)	0.003*
Secchi (m)	0.48 (0.03)	0.48 (0.03)	0.73
Slope (%)	7.92 (1.46)	9.87 (1.43)	0.01*
Temperature (C)	18.16 (0.95)	18.57 (0.91)	0.56
% Fine	42.2% (13.7%)	27.7% (13.5%)	0.008*
% Sand	33.4% (5.6%)	47.1% (4.9%)	0.07
% Wood[A]	18.5% (5.7%)	31.6% (4.8%)	0.02*

* Indicates significant results

[A] Mean calculated using untransformed data for easier
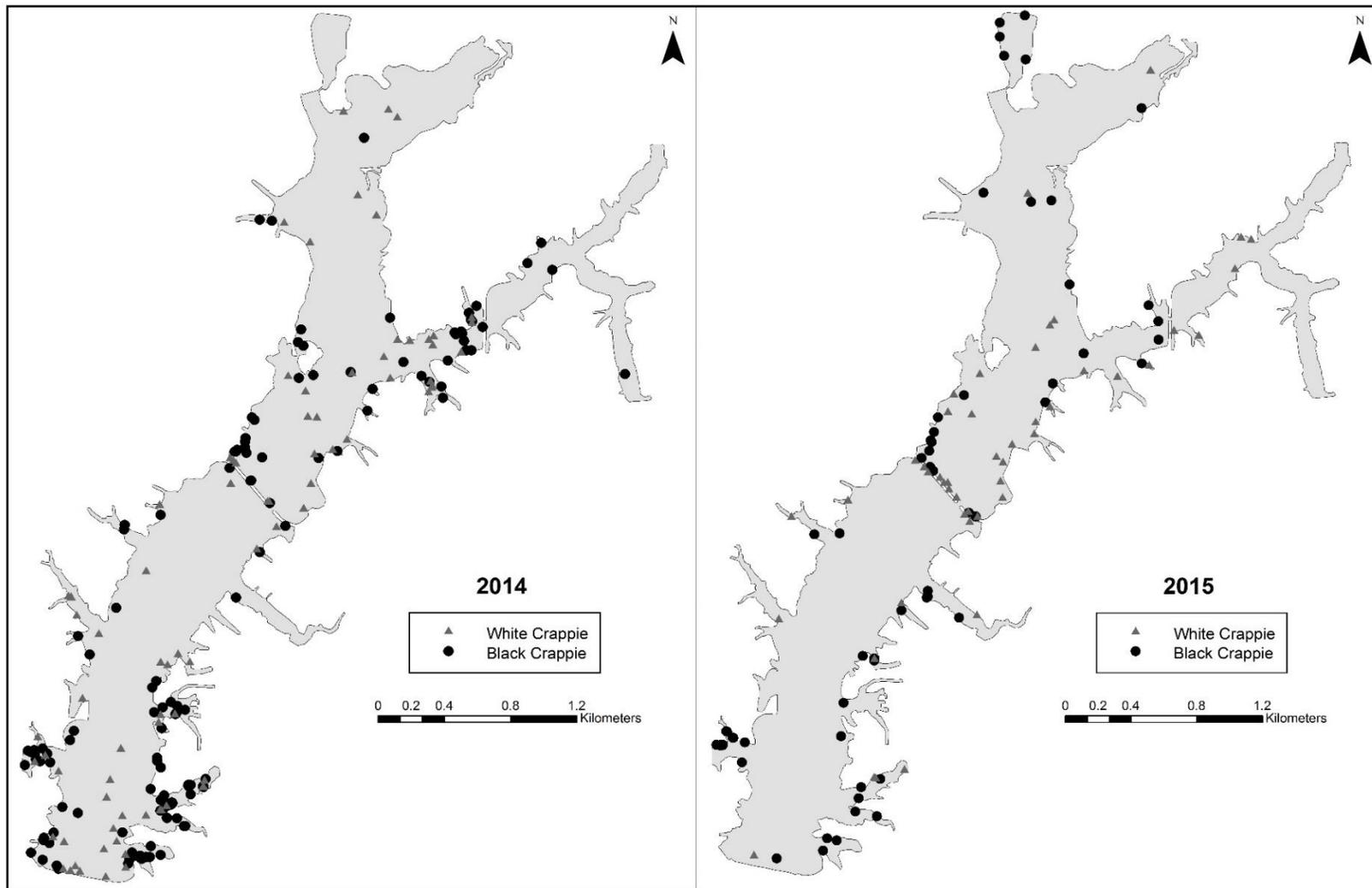interpretation.

Figure 3.1. Locations of black Crappie and white Crappie in Lake Mattoon, Illinois tracked weekly via active telemetry in 2014 and 2015
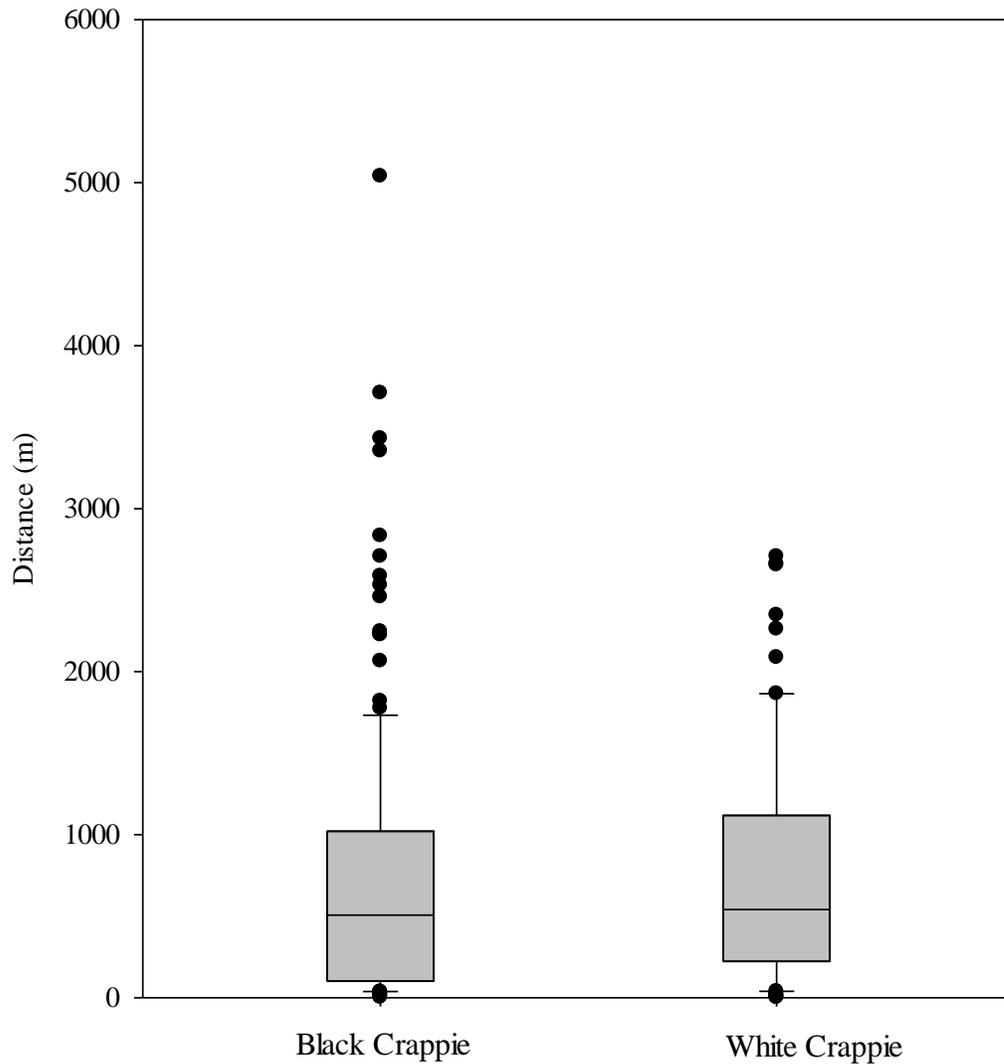
Figure 3.2. Mean weekly distance traveled by black crappie and white crappie released into Lake Mattoon in 2014 and 2015 with radio telemetry tags. The box plot represents the 25th and 75th percentiles, the inner line represents the median, and the whiskers represent the 10th (lower) and 90th (upper) percentiles.
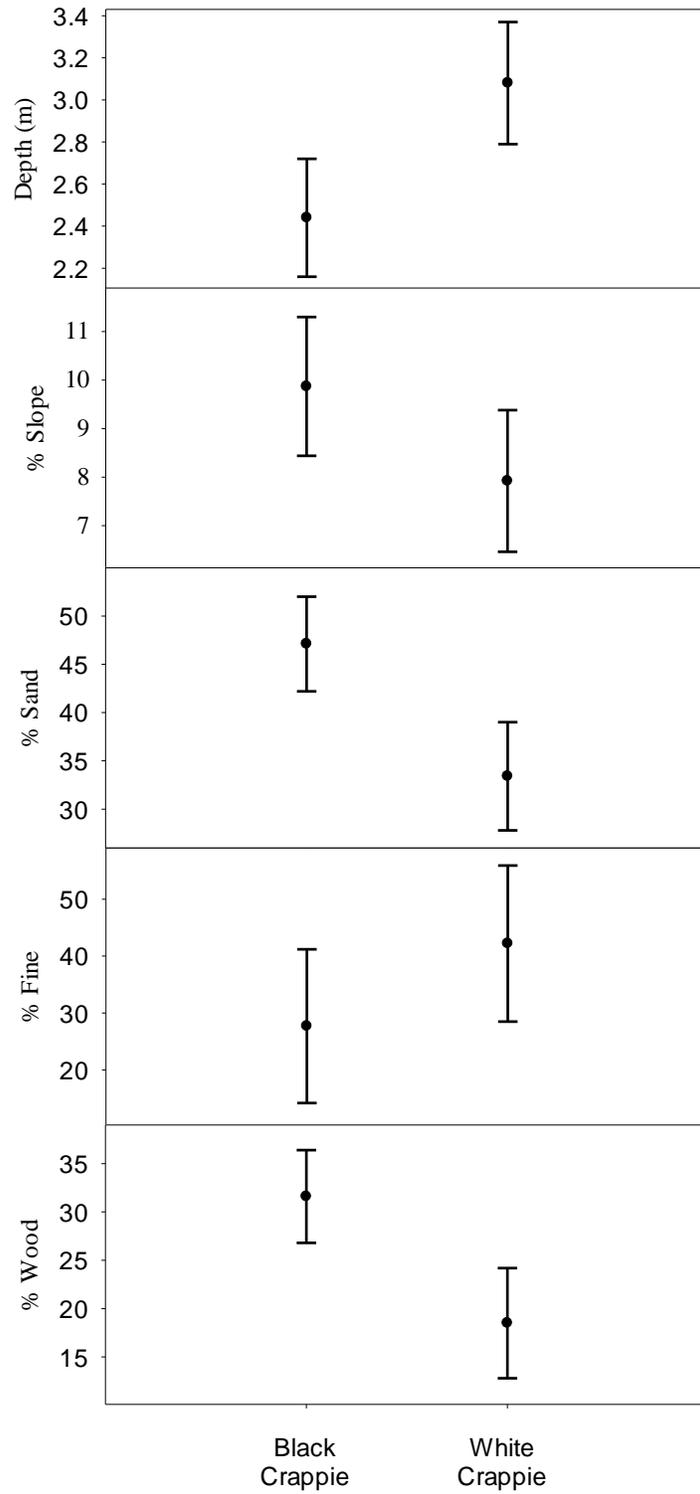
Figure 3.3. Mean habitat use of black crappie and white crappie released into Lake Mattoon in 2014 and 2015 with radio telemetry tags. Error bars represent standard errors.

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Chapter 4: Effectiveness of Three Attachment Methods for Saddle Style Telemetry Tags on Crappie

Abstract

Advancements in telemetry technologies have led to an increase in ecological studies of fishes, as new tags are less expensive, more accurate, and can be used on smaller bodied species due to reductions in tag size and weight. Proper testing of tag attachment methodology is currently lacking for some tag designs, leading to possible complications when used in field settings. We tested three attachment methods for saddle style tags: dorsal musculature attachment, dorsal spine attachment, and dorsal spine attachment with a marine-grade epoxy. Onset and incidence rate were recorded for tag loss, tag shifting, irritation, fungal growth, scale loss, and necrosis, and was compared across methods. Dorsal musculature attachment had no tag loss; however, fish developed irritation, necrosis, scale loss, and fungal growth around the site of the tag. Dorsal spine attachment fish had no necrosis or scale loss; however tag shifting occurred at a high rate and led to early tag loss. The addition of epoxy to the dorsal spine attachment methodology had no adverse effect on fish and increased tag retention time. Fish developed irritation and fungal growth in both dorsal spine methods; however it was less severe than fish tagged with the dorsal musculature method. Although dorsal spine attachment with epoxy had the longest retention time with minimal adverse effects to fish, a ten week average retention time limits the applicability of this methodology for field studies.

Introduction

Advancements in microchip and battery technologies have led to the development of new and improved telemetry gear (Hussey et al. 2015). New models of radio tags have increased

detection range and battery life, and are housed within a smaller package that facilitates their use on smaller species. Freshwater fisheries are greatly benefiting from these technological advancements, as smaller bodied species that once were too small for radio tagging can now be studied (Ovidio et al. 2009; Weimer et al. 2006). Greater availability of tags has increased the usage of radio telemetry to monitor fish location, behavior, habitat association, and movement (Hussey et al. 2015; Ovidio et al. 2009; Weimer et al. 2006; Cooke et al. 2008).

Three primary methods of transmitter attachment are found in the fisheries literature: surgical implantation, gastric implantation, and external attachment (Liedtke and Rub 2012). Each method of attachment has various advantages and disadvantages. Surgical implantation of a tag produces no drag or entanglement risk and allows for the use of internal sensors, but requires invasive surgical procedures that require a high degree of skill and can lead to infection (Liedtke and Rub 2012; Mellas and Haynes 1985). Gastric implantation also produces no drag or entanglement risk and can be done relatively quickly with little to no anesthesia. Conversely, gastric implantation can lead to tags being regurgitated or egested, and can lead to irritation or even rupturing of organs (Armstrong and Rawlings 1993; Liedtke and Rub 2012). External attachment can be accomplished relatively quickly and usually requires less invasive procedures than surgical implantation. However, external transmitters can lead to increased drag or fouling which can affect swimming efficiency and therefore behavior (Liedtke and Rub 2012; Ross and McCormick 1981). External attachment can also lead to infection at the attachment site, and is not suitable for rapidly growing fish (Weimer et al. 2006).

Improvements in technologies have led to an increased availability of external tag designs suitable for smaller bodied species. Saddle style tags are one example of a design well suited for smaller bodied species. The weight of a saddle style tag is evenly distributed across the dorsal

musculature of the body, minimizing impacts to balance and swimming ability (Liedtke and Rub 2012). The use of such tags on novel species requires testing to determine if the new tag is appropriate for use on that particular species (Jepsen et al. 2002). Differences in behavior, environment, or physiology of a species could have an effect on the suitability of certain tag designs (Mellas and Haynes 1985).

The most common external attachment methods involve suturing the tag directly to the body using a wire or cord material (Liedtke and Rub 2012; Weimer et al. 2006). Two or more sutures are passed through musculature and attached to a plastic backing, or in the case of a saddle tag to the other side of the tag (Weimer et al. 2006). These methods keep the tag tightly secured to the area in which the sutures are passed through and minimizes the risk of fouling or snagging. The majority of studies attach tags to the dorsal musculature; however, other parts of the body are occasionally used (Mellas and Haynes 1985; Thorstad et al. 2013; Claireaux and Lefrancois 1998). In this study, we compare the effectiveness of three variations of external attachment – dorsal musculature attachment, dorsal spine attachment, and dorsal spine attachment with epoxy - using a novel saddle style tag on a relatively understudied species, the black crappie (*Pomoxis nigromaculatus*).

Methods

Black crappie were obtained from rearing ponds at the Sam Parr Biological Station, INHS where they were used as brood stock. All crappie weighed over 225 grams to ensure that tags were less than two percent of their weight (Winter 1977). Fish were transported to the Kaskaskia Biological Station, INHS, held indoors in circular tanks (2 m diameter), and monitored for two weeks prior to the start of the experiment. Dummy versions of Advanced

Telemetry Systems (ATS) series F2200 saddle style radio tags were used to test the different attachment methods. Individual fish were anesthetized using a standard solution of Aqui-S. Fish were then placed on an operating table consisting of a plastic-covered foam trough that held the fish upright. Water containing a maintenance dosage of Aqui-S was constantly circulated over the gills via a small submersible pump and a piece of tubing placed 1-2 inches into the mouth of the fish. All tools and supplies were sterilized with ethyl alcohol before and between each individual surgery.

Surgical Attachment:

Dorsal musculature attachment

The first method consisted of using two 16-gauge needles and a piece of 24-gauge stainless steel wire to secure the tag. The two needles were passed between the pterygiophores of the third and fifth dorsal spine, approximately one centimeter down from the top of the dorsal musculature. A piece of 24-gauge wire, doubled over into a U shape, was first threaded through the two center pre-drilled holes on the battery side of the saddle tag. Each end of the wire was then threaded through the pointed end of its corresponding needle. The needles were then removed, leaving the ends of the wire exposed on the other side of the fish. The ends of the wire were then threaded through the corresponding pre-drilled holes in the microchip side of the transmitter. The two wire ends were then secured with a pair of clamping pliers and twisted until the wire was tightly securing the tag to the body of the fish. The tag end was then trimmed and bent over, which would be done in field use to minimize fouling by vegetation. The entire tagging process took no more than three minutes per fish.

Dorsal spine attachment/ dorsal spine attachment with epoxy

The second and third methods consisted of using two U-shaped pieces of wire to secure the tag to two of the dorsal spines. Two pieces of 24-gauge stainless steel wire were first inserted through two sets of pre-drilled holes in the battery side of the tag. The ends of the wire were then pushed through the connective tissue between the dorsal spines, so that the third and fifth dorsal spines were in between the two pairs of wire. The wires were then threaded through the holes on the microchip side of the tag, twisted until tight, trimmed, and bent over. The third method, dorsal spine with epoxy, was identical to the dorsal spine method with the exception that a binary marine-grade epoxy was applied to the inward facing sides of the tag before attachment.

Monitoring

Eleven fish were tagged using each method, (N = 33 total) and another nine untagged fish were added as controls to determine if any conditions occurred unrelated to tag presence. A stratified random approach was used to assign individuals to a tank, ensuring that each tank had at least one fish per method type including a control for a total of six fish per tank. Fish were monitored for tag loss on a daily basis during feeding and tank cleaning. Individuals with shed tags or those that had died, were measured for total length and weight, and inspected for any injuries. Live individuals who had shed the tag were returned to tanks, while replacement fish were added in the case of mortalities to maintain a density of six fish per tank. Once per week every individual was assessed for physiological and behavioral conditions as well as status of tag attachment. Fish were fed fathead minnows (*Pimephales promelas*) ad libitum for the duration of the experiment. The experiment was continued until the last individual tagged with either of the dorsal spine techniques shed its tag.

Analysis

In addition to tag loss and fish mortality, observations noted during monitoring fit into five basic conditions: tag shifting, dermal irritation, fungal growth, necrosis of muscle tissue, and scale loss. Tag shifting consisted of the positioning of the tag changing, usually in a partial rotation along the midsagittal plane. Dermal irritation consisted of inflamed areas of redness immediate to the tag location. Fungal growth consisted of the formation of fungal colonies on and around the tag location. Necrosis consisted of any open lesion and loss of musculature surrounding the location of the tag. Scale loss consisted of the loss of scales, usually along the lateral line, that often coincided with subcutaneous soft muscle degradation.

Week of onset and incidence rate were calculated for each of the seven conditions. Week of onset was measured as the first week in which a condition was observed. Incidence rate was calculated as the number of individuals within a given attachment method that displayed the condition at some point during the experiment. Due to a lack of normality within the data, a Wilcoxon signed-rank test was performed testing the median onset of tag shifting, irritation, fungal growth, and tag loss between the three methods, using a Holm-Bonferroni correction to control the experimentwise error rate. Chi square tests were used to compare the incidence rate of tag shifting, redness, and fungal growth between methods, using a Holm-Bonferroni correction to control the experimentwise error rate.

Results

Untagged fish remained healthy for the duration of the experiment and did not display any of the conditions observed in tagged fish. A single dorsal musculature individual was the only mortality during the entirety of the experiment. Median week of tag loss did not

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statistically differ between dorsal spine attachment (Week 5) and dorsal spine attachment with epoxy (Week 10, Z = 2.52, P = 0.01; Table 3.1).

Tag shifting occurred in individuals tagged with either dorsal spine method, but not those tagged with the dorsal musculature method. Median onset of tag shifting significantly differed between dorsal spine attachment (Week 2) and dorsal spine attachment with epoxy (Week 3, Z = 3.40, P = 0.01; Table 3.1). Incidence rate of tag shifting did not statistically differ between dorsal spine attachment (100%) and dorsal spine attachment with epoxy (55%, $\chi^2(1,22) = 8.42$, P = 0.01; Table 3.2).

Irritation was observed in all three methods, with dorsal musculature attachment (Week 2) displaying irritation significantly earlier than dorsal spine attachment (Week 3, Z = 3.73, P = 0.01; Table 3.1) and dorsal spine attachment with epoxy (Week 3, Z = 3.63, P = 0.01; Table 3.1). Onset of irritation for the dorsal spine methods did not significantly differ from one another (Week 3, Z = 0.77, P = 0.44; Table 3.1). Incidence rate of irritation in dorsal musculature attachment (100%) did not differ from dorsal spine attachment (72%, $\chi^2(1,22) = 3.47$, P = 0.06; Table 3.2) or dorsal spine attachment with epoxy (64%, $\chi^2(1,22) = 4.88$, P = 0.03; Table 3.2), nor did the dorsal spine methods differ from one another ($\chi^2(1,22) = 0.21$, P = 0.64; Table 3.2).

Fungal growth was observed in all three methods, with dorsal musculature attachment (Week 2) displaying fungal growth significantly earlier than dorsal spine attachment (Week 4, Z = 3.18, P = 0.01; Table 3.1), but not earlier than dorsal spine attachment with epoxy (Week 3, Z = 2.01, P = 0.04; Table 3.1). The dorsal spine methods did not differ in onset of fungal growth (Z = -1.51, P = 0.13; Table 3.1). The incidence rate of fungal growth was statistically higher in dorsal musculature attachment (100%) than in both dorsal spine attachment (46%, $\chi^2(1,22) = 8.25$, P = 0.01; Table 3.2) and dorsal spine attachment with epoxy (36%, $\chi^2(1,22) = 10.27$, P =

0.01; Table 3.2). The incidence rate of fungal growth did not differ between dorsal spine methods (χ^2(1,22) = 0.18, P = 0.66; Table 3.2).

Dorsal musculature attachment displayed necrosis (Week 3) and scale loss (Week 7) in all individuals except for when mortality occurred. Neither of the dorsal spine methods displayed necrosis or scale loss.

Discussion

The literature on telemetry tag attachment methodology suggests there is often a tradeoff between successful long-term securement of the tag and health of the fish (Liedtke et al. 2012; Ross and McCormick 1981; Jepsen et al. 2002). Tagging methods are often too invasive and lead to mortality, or they fall off prematurely. Our comparison of three tagging methods highlights these concerns. Fish tagged with dorsal musculature attachment, the most invasive of the three methods, demonstrated a wide array of conditions. A majority of fish developed dermal irritation and fungal growth on and around the tag location and displayed necrosis of the tissue surrounding the tag location that worsened throughout the experiment. Fish eventually displayed scale loss along the lateral line. Despite the necrosis of tissue around the tags, no tag loss was observed for the duration of the experiment. Given the severity of injury that occurred for fish with dorsal musculature attachment, mortality rates would have likely been greater had it not been for ad libitum feeding and the relatively hygienic environment in which they were housed. A field telemetry study using this attachment method found high mortality rates within 15 weeks (Garavaglia and Wahl in review). Of the three methods examined, dorsal musculature attachment was the only one in which fish developed necrosis or scale loss, leading us to conclude that dorsal musculature attachment is an undesirable option for crappie. These results likely apply to

other warmwater centrarchids; therefore testing should be conducted before using this tag type and methodology on other species.

Both dorsal spine attachment methods are less invasive than the dorsal musculature method. Necrosis and scale loss was completely absent in both dorsal spine attachment methods. Dorsal spine attachment fish also displayed irritation and fungal growth less often, and those that did contract these conditions did so later into the experiment. Irritation in dorsal spine fish was also less severe than irritation observed in the dorsal musculature fish, and was often limited to the interradial membrane immediately surrounding the tag.   The noninvasive nature of this method, however, did lead to early shifting of the tag in all fish, which subsequently led to the loss of all tags between three and nine weeks after attachment. The short retention time limits the suitability of this methodology for field applications.

Addition of marine-grade epoxy to the dorsal spine attachment methodology was evaluated with the goal of increasing tag retention time without causing any negative impacts to fish. As was hypothesized, the addition of epoxy appears to have improved attachment. Fish with epoxy had a lower occurrence and later onset of tag shifting as well as a later onset of tag loss. Although epoxy increased the average retention time by five weeks, the increase was not statistically significant, largely due to the high level of variability in week of tag loss. Tag loss in fish with epoxy was bimodal, with three fish losing their tags between 3 and 5 weeks, whereas the other eight lost them between 9 and 16 weeks. We suspect the three fish who lost their tags early may have had their epoxy fail due to error in application or hardening of the epoxy around the dorsal spines, thus their similarity in time of tag loss to those tagged without epoxy. The addition of epoxy did not change the onset or occurrence of either irritation or fungal growth.

A proper method for attaching saddle tags to black crappie and other warmwater centrarchids is currently lacking. The methods that we tested were the result of numerous conversations with other biologists and experts in the field of telemetry attachment, as well as an extensive literature search. A common theme is the inability to maintain saddle transmitters on warmwater species for more than several weeks (Weimer et al. 2006; Ross and McCormick 1981). Our study assessed several options for saddle style transmitter attachment, and their unique yet inevitable complications. Further development of attachment methodology is necessary before saddle style transmitters should be used for management applications in which tag retention greater than several weeks is required.

Table and Figure

Table 4.1. Medians and interquartile ranges (in parentheses) of the onset of each condition and incidence rate by the end of the experiment for three saddle style tagging methods. Black crappie were tagged with either dorsal musculature, dorsal spine, or dorsal spine with epoxy attachment methods and held for 16 weeks in 2 m diameter tanks at a density of six fish per tank.

Method	Tag Loss	Shifting	Irritation	Fungus	Necrosis	Scale Loss
			First Week of Occurrence (Onset)			
Musculature	-	-	2 (0)	2 (0)	3 (0)	7 (1.0)
Spines	5 (2.0)	2 (1.0)	3 (0.3)	4 (0)	-	-
Spines + Epoxy	10 (7.5)	3 (1.5)	3 (1.0)	3 (0.5)	-	-
			Incidence Rate			
Musculature	-	0	100	100	91*	91*
Spines	100	100	72	46	0	0
Spines + Epoxy	100	55	64	36	0	0

* Dorsal musculature attachment had a mortality at Week 3. Necrosis and scale loss were observed in 100% of remaining fish.
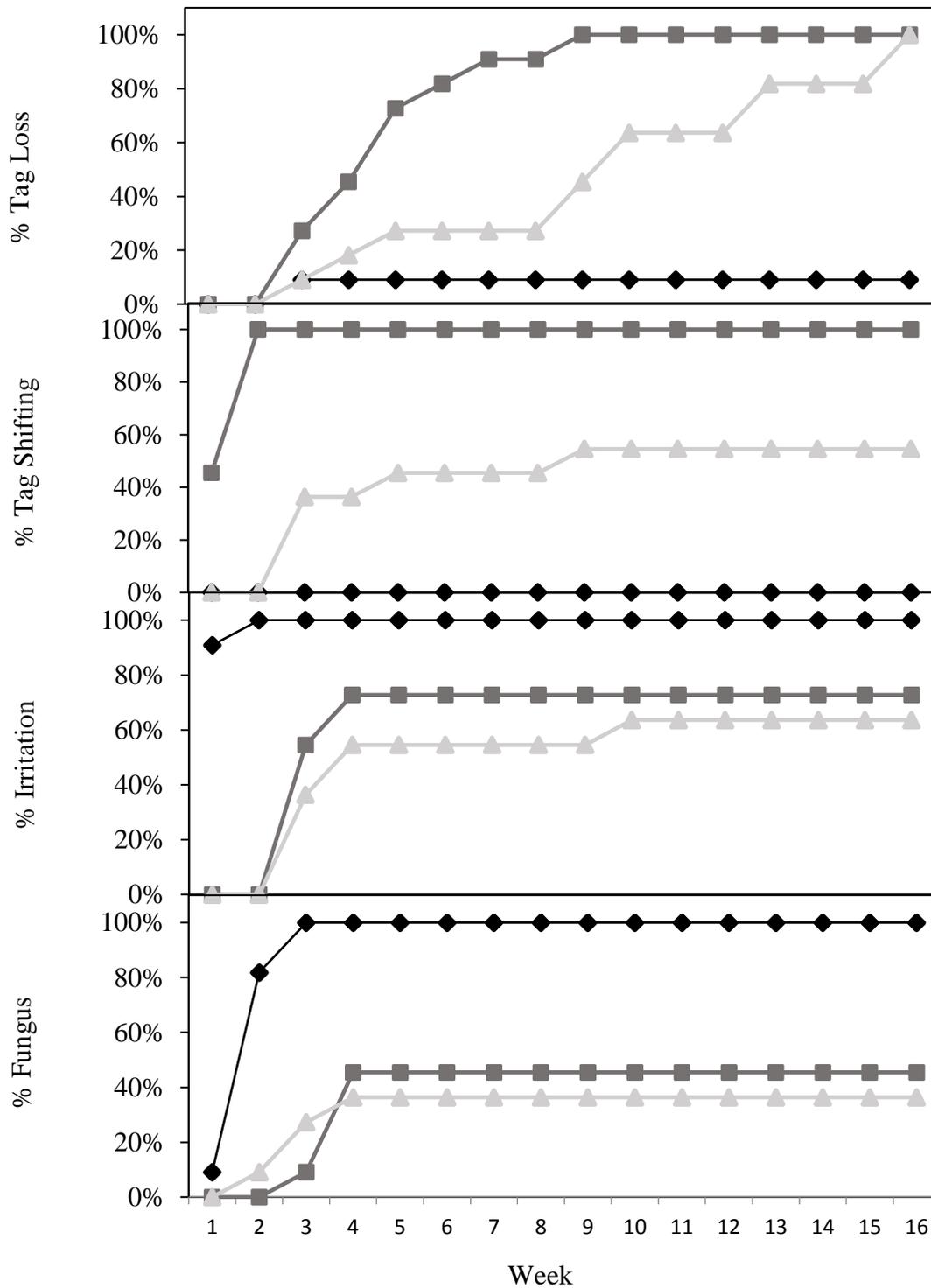
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Figure 4.1. Cumulative onset of tag loss, tag shifting, irritation, and fungal growth for black

crappie tagged with saddle-style tags on the dorsal musculature (black diamonds), dorsal spines

(Dark gray squares), and dorsal spines with epoxy (light gray triangles).

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Conclusions

Crappie provide an important fishery in many lakes and rivers across the central and southern United States. Crappie fisheries have social, economic, and ecological benefits, but managing them to maximize these benefits is challenging. The variability in recruitment and growth often observed in crappie populations can lead to an inconsistent fishery. Although black crappie and white crappie are two closely related species, they appear to differ in many aspects of their ecology. These differences in ecology may contribute to the difficulty in understanding the fundamental links between recruitment variability and environmental conditions, particularly when these two species are grouped during analyses. Recent research has shed light on the importance of these differences; however, fisheries managers often continue to group both species together when making management decisions.

I investigated the differences in ecology between black crappie and white crappie in an attempt to better understand the environmental parameters that lead to variable recruitment and growth. I found that recruitment strength of white crappie was negatively related to the abundance of common carp and largemouth bass, whereas the recruitment strength of black crappie increased with gizzard shad abundance. White crappie first-year growth was positively related to both temperature and zooplankton whereas black crappie first-year growth was positively related to temperature but negatively related to zooplankton. I believe the differences I observed between black crappie and white crappie recruitment and growth are related to differences in diet. White crappie switching to piscivory leads to different reactions to environmental conditions as compared to black crappie that often remain benthivorous. Factors affecting pelagic zooplankton and small fish appear to affect white crappie, whereas factors affecting littoral invertebrate prey appear to effect black crappie.

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Differences in diet may also be the explanation for the differences in habitat use I observed between black crappie and white crappie. Over two spring seasons, I observed black crappie utilizing shallow locations with sandy bottoms, steep bathymetric slopes, and coarse woody debris. White crappie were observed utilizing deeper locations with gradual bathymetric slopes and fine sediments, and did not utilize coarse woody debris as often as black crappie did. I believe black crappie used littoral areas with coarse woody debris because these locations are ideal for benthic prey. Littoral areas have higher inputs of allochthonous material such as leaf litter and coarse woody debris. These materials provide food and shelter for the invertebrate communities that black crappie prey upon. White crappie likely utilized pelagic locations due to the presence of young-of-year gizzard shad and other piscivorous food sources located in the pelagic zone.

Unfortunately, we were only able to observe habitat use during the spring season due to complications with tag retention. In a controlled laboratory experiments we tested three methods of attachment for saddle style radio telemetry tags. We found that any area in contact with the tag would develop irritation and necrosis. The most successful attachment method involved attachment to the dorsal spines with the addition of a marine epoxy, however even this method only produced an average retention time of ten weeks. Further research into the movement and habitat use of crappie using telemetry will need to develop an effective attachment method for saddle style tags, or opt for internal tag designs.

Though beyond the scope of this research, I hypothesize that the differences in diet between these two species, and the concomitant differences in ecology I observed, may have evolved as a form of niche partitioning allowing both species to cohabitate with decreased interspecific competition. An analysis into the genetic, physiological, and behavioral differences

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between black crappie and white crappie may help explain some of the differences observed in their ecology. Further research into crappie ecology should focus on the interspecific differences in diet, habitat use, and interactions with environmental variables to better understand the underlying mechanisms affecting crappie recruitment and growth. Fisheries managers should also focus on these differences and manage each species of crappie separately if they are to successfully manage populations of crappie.