A literature review of management approaches based on rate functions associated with black and white crappie populations

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Introduction

This literature review is a project of the Wisconsin Department of Natural Resources (WDNR) Panfish Standing Team. In Wisconsin, "panfish" traditionally has been regulated as a broad group that includes several genera – the sunfishes (*Lepomis* spp.), the crappies (*Pomoxis* spp.), and yellow perch (*Perca flavescens*). The Panfish Team is responsible for assembling and summarizing technical information to advise the WDNR Fisheries Management Board on matters of statewide panfish management policy and strategy.

The scope of this review is limited to the peer-reviewed scientific literature and several agency reports deemed relevant to the ecology and management of inland populations (excluding the Great Lakes and Mississippi River) of black crappie (*Pomoxis nigromaculatus)* and white crappie *(Pomoxis annularis)* in Wisconsin. This review is structured sequentially around the primary rate functions influencing fish populations – reproduction, growth, recruitment, and mortality. A description of relevant information related to each of these rate functions is presented for black and white crappie. The literature included in this review does not represent an exhaustive review of all available information for these species. Instead, in the interest of focus, we limited our search to information of direct utility to Upper Midwestern fishery managers.

Crappie

Black Crappie Distribution and Habitat

Black crappie are common in lakes and larger rivers, and occur in all three drainage basins in Wisconsin. This glacial species is well distributed throughout the state, except in the streams of the Driftless area of southwestern Wisconsin. Black crappie originally did not range through the central and north central portions of the state, but were likely introduced into this area through stocking efforts (Becker 1983).

Black crappie are usually found in the clear, quiet, warm water of ponds, small lakes and bays, shallow waters of large lakes, sloughs, backwaters, and landlocked pools (Figure 1). They are almost always associated with abundant growths of aquatic vegetation. In Wisconsin, they are encountered in clear to slightly turbid water, over substrates of sand, mud, gravel, silt, rubble, boulders, clay, hardpan, and detritus. They occur in streams of varying widths. Black crappies prefer clearer, deeper, and cooler waters than does the white crappie (Schneberger 1972). In winter, black crappie seek out relatively well oxygenated (>2 mg/L), warm areas (>1°C), with minimal flow (<1 cm/s, Knights et al. 1995).

Black crappie existing in chains of lakes or other types of interconnected waterbodies can be very mobile. A tagging study by Parsons and Reed (2005) in four Minnesota lakes estimated annual emigration from a lake to be between 0 and 92%. Fish of all sizes appeared to emigrate at similar rates and there was no preference for upstream or downstream movement.

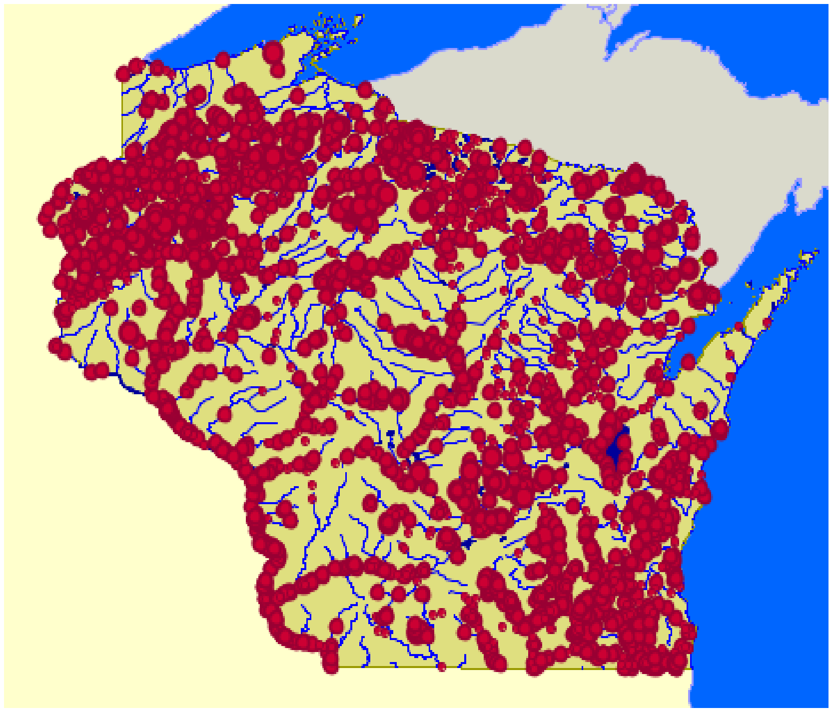

Figure 1. Black crappie distribution in Wisconsin (Lyons 2012)

White Crappie Distribution and Habitat

In Wisconsin, white crappies occur in the Mississippi River and Lake Michigan drainage basins, near the northern limit of their distribution. White crappies have not been sampled in the Lake Superior watershed. Although some range extension was likely a result of species natural expansion into suitable habitats, some also resulted from the intended or the inadvertent stocking of white crappie with other species (Green 1935, Scheneberger 1972). In addition to extending its range in Wisconsin, the white crappie appears to be increasing in population size (Becker 1983).

In Wisconsin, white crappies occur in sloughs, backwaters, landlocked pools and lakes, and in the pools and moderate currents of moderate-sized to large streams (Figure 2).

They inhabit areas of sparse vegetation and prefer slightly turbid to turbid water, of varying depths within warm, shallow water, over substrates of sand, mud, gravel, rubble, clay, and silt (Becker 1983). Spawning activities are largely similar to that of black crappie. Hybridization between black and white crappie is possible but rare in the wild because of reproductive isolation (Miller et al. 2008; Epifanio et al. 1999).

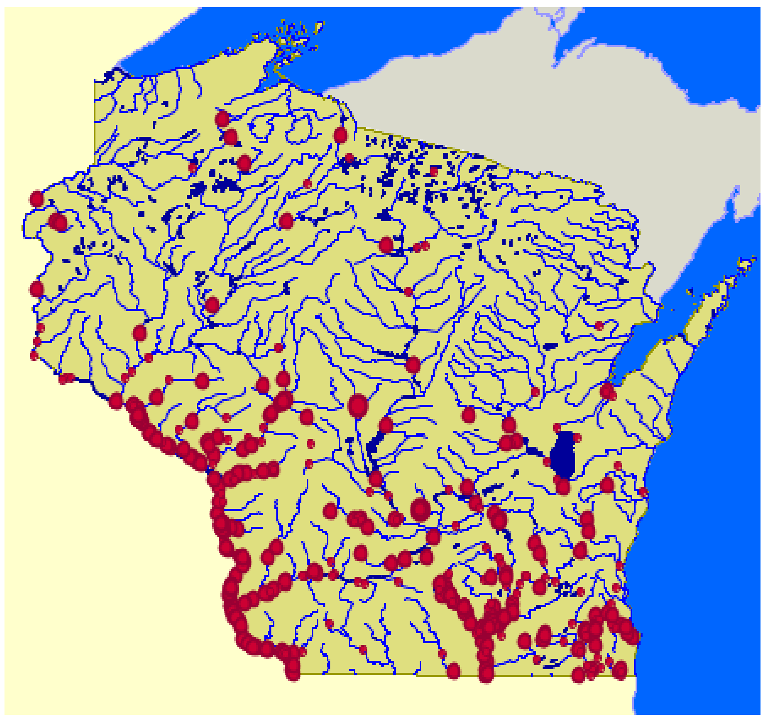

Figure 2. White crappie distribution in Wisconsin (Lyons 2012).

Recruitment

Abiotic Factors Affecting Recruitment

Water temperature plays an essential role in determining when spawning occurs for both black and white crappie. White crappie spawn in nests built in colonies in water between 0.05-1.5 m during May and June in Wisconsin when water temperatures are between 12-23º C, although most spawning occurs between 16-20º C (Becker 1983). Black crappie spawning activities are characteristically similar to those of white crappie and they also construct and guard nests built in colonies primarily in May and June when water temperatures are between 18-20º C. Black crappies seek out warmer areas that are protected from wind and wave action to build nests and often associate with woody debris (Pope and Willis 1997). Phelps et al. (2009) found black crappie selected nest sites in proximity to deep water with firm substrates and low vegetation height and density. Unlike white crappie, black crappies will abandon their nests if water temperatures revert to temperatures below those suitable for spawning. Pine and Allen (2001) found that water temperatures influenced growth and survival of juvenile black crappie when later hatching fish experiencing higher water temperatures exhibited higher daily growth and survival in Lake Wauberg, Florida. However, Pine and Allen (2001) speculated that this result was likely to vary with other environmental factors such as spring storm events. Similarly, Parsons et al. (2004) found weak crappie year classes in Minnesota lakes in years when June and July were colder than average. In contrast, St. John and Black (2004) found no correlation between water temperature and abundance of age-0 crappie in J. Percy Priest Reservoir, Tennessee.

Black crappie recruitment can also be affected by physical and chemical characteristics of a waterbody. Guy and Willis (1995) found decreased variability in recruitment of black crappie in systems with high shoreline development indices and high watershed area: surface area ratios. Bunnell et al. (2006) found that productivity, as measured by chlorophyll concentration, explained a significant amount of variation in crappie larval recruitment with higher chlorophyll levels being associated with higher larval densities.

Similarly, Allen et al. (1998) found that age-0 black crappie density was positively related to chlorophyll concentration in 60 lakes in Florida. Conversely, Dubuc and DeVries (2002) found no clear relationship between reservoir productivity and larval crappie density.

Water levels during pre-spawning and spawning periods have been shown to have a large effect on crappie recruitment. Sammons et al. (2002) found a positive relationship between high discharge levels during the pre-spawn period and crappie recruitment in storage reservoirs in Tennessee. During the spawning period however, Sammons et al. (2002) presented mixed results with the relationship between discharge and crappie recruitment being significant and positive in one reservoir and significant and negative in another. Similarly, Sammons and Bettoli (2000) found that crappie recruitment was positively related to precipitation and discharge levels in the pre-spawn period. Maceina and Stimpert (1998) found in stable reservoirs, with low retention times (i.e. less than nine days), high crappie recruitment was associated with low retention time in winter followed by a longer retention time in the post-spawning period. In reservoirs with more highly variable water levels, Maceina and Stimpert (1998) found high crappie recruitment to be associated with short winter retention and higher water levels. The majority of the results of Maceina and Stimpert (1998) were verified by Maceina (2003). Beam (1983) found that higher water levels were significantly related to year class strength of white crappie, and that fluctuations in water levels were significantly negatively related to year class strength in a Kansas reservoir. Beam (1983) suggested that higher water levels may increase access to spawning habitat and afford greater protection for larvae. Similarly, Miller et al. (1990) found the highest black crappie recruitment in years with the highest water levels in Lake Okeechobee, Florida. Maceina et al. (1996) suggested that short retention times in reservoirs could reduce phytoplankton densities and negatively impact the survival of juvenile crappies.

Biotic Factors Affecting Recruitment

Size of spawning stock plays a role in determining the amount of recruitment in crappie populations. Bunnell et al. (2006) found that a combination of spawning stock catch per effort and chlorophyll level explained 74-86% of the variation in the catch per effort of recruits in 11 reservoirs in Ohio. Bunnell et al. (2006) went on to suggest that the number of recruits was more strongly related to spawning stock density when densities were low compared to when they were high. Similarly, Allen and Miranda (1998) found that spawning stock density explained between 9 and 44% of crappie recruitment variability in recruitment to age-1 in four reservoirs in the southern United States. However, several studies were unable to detect a relationship between spawning stock density and recruitment. Miranda and Allen (2000) suggested that in crappie populations where recruitment fluctuates greatly harvest length limits will do little to attenuate the variability in recruitment, which suggests that the relationship between spawning stock and recruitment is not strong. Similarly, McKeown and Mooradian (2002) found no relationship between adult density and age-0 crappie abundance in Chautauqua Lake, New York. Pope and Willis (1998) found little correlation between peak larval abundance of crappie and fall catch of age-0 recruits. Environmental variables appear to have a broad and powerful influence of year class strength while density of adults is a contributing but less important factor (Pope and Willis 1998; Parsons et al. 2004).

Competitive and predatory interactions between crappie and other fish species can limit crappie recruitment. McKeown and Mooradian (2002) showed that age-0 crappie abundance was positively associated with the biomass of walleye prey, including yellow perch (*Perca flavescens)*, sunfish (*Lepomis* spp.*)*, and white perch (*Morone americana*), and negatively associated with walleye abundance, suggesting that walleye can affect crappie recruitment and that alternate prey species can buffer the effects of walleye predation on juvenile crappie. Carline et al. (1984) used a bioenergetics modeling approach to examine predator prey relationships in impoundments and concluded that largemouth bass *(Micropterus salmoides)* would not control numbers of bluegill *(Lepomis macrochirus)* or crappie when alternative preferred prey (i.e. gizzard shad) were present. Pope (1996) found a negative association between relative abundance of young of year perch and black crappie year class strength that was believed to be the result of competitive interactions. However, Parsons et al. (2004) did not find any negative associations between these species in a study of four Minnesota lakes. Muskellunge *(Esox masquinongy)* do not appear to have a significant effect on crappie populations. Knapp et al. (2008) evaluated changes in crappie populations following the introduction of muskellunge in a set of Minnesota lakes and found no change in relative abundance in most lakes and an increase in abundance in one class of lakes.

Managing Recruitment

Although physical and chemical characteristics affect crappie recruitment (Guy and Willis 1995, Bunnell et al. 2006, Allen et al. 1998), the relationships are sometimes not clear (Dubuc and DeVries 2002). Similarly, physical characteristics such as watershed:surface area ratios may affect crappie recruitment, but would be extremely difficult to manipulate. Although productivity may be associated with recruitment (Allen et al. 1998), artificially increasing productivity may have undesirable and unintended consequences.

Many studies have linked crappie recruitment to water level and discharge rates. Although few reservoirs in Wisconsin have discharge rates that can be manipulated to the degree as those studied in Sammons et al. (2002), Sammons and Bettoli (2000), Maceina and Stimpert (1998) and Maceina (2003), high and stable water levels should be encouraged if recruitment is limiting (Maceina and Stimpert 1998, Beam 1983, Miller et al. 1990).

Increasing spawning stock densities above a threshold level through harvest restrictions may increase recruitment. Low spawning stock abundances have been associated with low levels of recruitment (Allen and Miranda 1998, Bunnell et al. 2006) so in some cases it may be desirable to increase the spawning stock by limiting harvest. However, further increases in spawning stock densities may not result in increased recruitment as other authors suggest that spawning stock may not be strongly linked to recruitment (Miranda and Allen 2000, and McKeown and Mooradian 2002). Miranda and Allen (2000) modeled the effects of minimum length limits on crappie recruitment and adult density. Increasing minimum harvest length (from 8 to 10 to 12 inches) resulted in increasing density of adult crappie and decreasing density of recruits. The implementation of minimum length limits in this modeling exercise was found to successfully stabilize numbers of adult crappie which otherwise can vary in a “quasi-cyclic” pattern related to the amount of recruitment in previous years. Recruitment was still highly variable in these scenarios as a result of variation in environmental variables that are not under the influence of fishing regulations.

Predation may limit crappie recruitment (McKeown and Mooradian 2002). If crappie predators, such as walleye, are abundant, crappie recruitment may improve if predator populations are reduced through harvest. Grant et al. (2004) found a significant decrease in crappie gill net CPUE that coincided with an increase in walleye CPUE in a large set of Minnesota lakes suggesting an inter-specific interaction. Ellison (1984) concluded that managing predators was a key component of effective crappie management and recommended maintaining moderately high densities of predators to limit recruitment and improve growth rates.

Understanding the amount of variation in year class strength of a given lake is key to selecting management actions and setting monitoring plans. In a study of small Minnesota lakes Parsons et al. (2004) found few instances of weak or missing year classes. In these cases, tools developed to describe and predict year class strength such as the recruitment variability index (Guy and Willis 1995) or the recruitment coefficient of determination (Isermann et al. 2002a) may be of little use. The authors go on to conclude that when recruitment is stable, minimum length limits may be effective to improve size structure, but when recruitment varies widely, bag limits are a more effective tool to limit harvest with the understanding that increased density may limit growth and the ability of fish to reach the minimum length limit.

Growth

Accurate methods to easily and non-lethally determine the sex of individual crappie based on coloration, abdominal distention, and gamete stripping have been described and can easily be utilized by managers (Isermann 2010). However, Isermann et al. (2010) examined populations of black crappie in five Minnesota lakes and found little evidence of sex-specific growth rates or length-weight relationships. The authors state that managers are justified in pooling both sexes when calculating growth and that minimum length limits are unlikely to promote sex specific harvest that could alter population sex ratios. Jackson and Hurley (2005) provide average growth rates (broken down by percentile) for both black and white crappie populations in the United States. These values may be useful for managers as a basis of comparison for individual populations, but more localized growth standards may provide greater utility due to the strong influence of southern populations on growth rates reported by Jackson and Hurley (2005). McInerny and Cross (2008) provide length at age data for a large set of Minnesota lakes and rivers with data further subdivided by lake class, which may be more useful to upper Midwestern fish managers.

Abiotic Factors Affecting Growth

Pine and Allen (2001) found that the daily growth rate of larval black crappie was positively related to spring water temperature. McInerny and Cross (2008) found higher length at age in southern Minnesota crappie populations in comparison to northern populations. However, Hale (1999) found that growth declined with increased water temperature in a Kentucky reservoir and suggested that summer water temperatures of 27ºC and higher may suppress growth of white crappie.

Biotic Factors Affecting Growth

The amount of forage available for both juvenile and adult black crappie may act as a factor that can influence growth. Several studies have found crappie diets to be largely made up of zooplankton and invertebrates (primarily dipteran larvae) in early summer, with young of year fish prey becoming a more important diet item for larger crappie as summer progresses (Lux and Smith Jr. 1960, Seaburg and Moyle 1964). Bunnell et al. (2003) found abundance of zooplankton to be linked to growth rates of larval crappie. Keast (1968) documented adult black crappie consuming yellow perch, bluegill, pumpkinseed *(Lepomis gibbosus)*, blackchin shiner *(Notropis heterodon)*, golden shiner *(Notemigonus crysoleucas)*, fathead minnow (*Pimephales promelas)*, largemouth bass, and smallmouth bass *(Micropterus dolomieu)* in Lake Opinicon Ontario. McInerny and Cross (2008) found yellow perch and bluegill to be important diet items of crappie, particularly for larger size classes. Ellison (1984) found black crappie never shifted to fish prey in a turbid Nebraska impoundment. Ellison (1984) hypothesized that black crappie were unable to effectively capture fish prey in turbid water which may explain the higher abundance of white crappie over black crappie in these types of systems.

Although the link between forage availability and growth is intuitive, the direct relationship between forage availability and black crappie growth is often seen as weak. Allen et al. (1998) suggested that black crappie density in Florida lakes was related to growth in a quadratic fashion, and density was best predicted by zooplankton abundance although this relationship was weak. Essentially, Allen et al. (1998) associated the highest growth potential with populations that existed in lakes with high densities of zooplankton. Ellison (1984) found growth rates of planktophagic white and black crappie to decrease as individuals reached 150 mm and small zooplankton prey became less profitable to pursue. Growth rates then increased when crappie shifted to fish prey at around 200 mm. McInerny and Cross (1999) also found that black crappie growth increased with increasing chlorophyll concentration, the implication being that greater chlorophyll concentration would result in increased zooplankton density. Mosher (1984) found mixed results of an effort to increase black crappie growth through stocking of threadfin shad *(Dorosoma petenense)*, and Devries and Stein (1990) found mixed responses of black crappie population to shad population manipulations in a survey of a number of different studies and suggested that competition between juvenile crappies and shad for zooplankton could limit the success of these efforts. McInerny and Cross (2008) identified negative relationships between crappie length at age and relative abundance of bluegill and pumpkinseed that provide evidence of competition limiting growth.

The intensity of predation on black crappie can influence growth. Higher levels of predation can result in reduced densities of black crappie populations which in turn increases growth. The relationship between black crappie growth and the presence and/or abundance of several piscivores has been examined. Gabelhouse (1984) found that proportional stock density (PSD) scores for both black crappie and white crappie were inversely proportional to largemouth bass PSD, and suggested higher densities of largemouth bass less than 15 inches can reduce crappie densities and intraspecific competition allowing crappies to attain larger sizes. Galinat et al. (2002) suggested that saugeye predation on black crappie in a lake in Minnesota reduced abundance and intraspecific competition of small black crappies, which resulted in increased growth and improved size structure of the remaining black crappies. Similarly, McInerny and Cross (2008) found longer length at ages 3-5 inch crappie populations as walleye gill net CPUE increased. Neal et al. (1999) found that black crappie total length and relative weight increased as a result of predation from stocked hybrid striped bass (*Morone saxatilis* × *Morone chrysops*). The effectiveness of northern pike *(Exox lucius)* as a predatory control of crappie abundance and an enabler of fast growth is conflicting in the literature. Willis et al. (1984) suggest that northern pike predation was a factor in maintaining desirable black crappie size structure in a small impoundment in Colorado. Conversely, McInerny and Cross (2008) found growth rates of crappie to be high when northern pike density was low.

Suitable black crappie habitat is thought to influence growth. Percent cover, which includes vegetation, brush, and debris, is a factor that weighs heavily in a black crappie habitat suitability model developed by Edwards et al. (1982). Edwards et al. (1982) suggest that the optimal amount of cover for black crappies is between 25-85% and suggest that aquatic vegetation is particularly important for growth and reproduction. Valley et al. (2004) suggest that conditions for game fish deteriorate when the percentage of submersed aquatic vegetation falls below 10% or exceeds 60%. Similarly, Schneider (2000) found increased black crappie size structure in a number of Michigan lakes after levels of Eurasian watermilfoil *(Myriophyllum spicatum)* were reduced and other plants recolonized. However, Allen et al. (1998) found that black crappie growth was not affected by macrophyte abundance in Florida lakes.

Population density is the primary determinant of black crappie growth. Growth is density dependent with higher densities generally causing slower growth, presumably due to resource limitations. However, Allen et al. (1998) found that growth declined with density up to a point and then increased with increasing density. Guy and Willis (1995) found that length at age, PSD, and RSD were inversely proportional to density in 22 black crappie populations in South Dakota and that growth varied by ecosystem type (i.e. natural lakes, small impoundments, and large impoundments). Hale et al. (1999) found that growth did not change in an Ohio reservoir after the institution of a 10 inch minimum length limit despite modest increases in density. Prior to the length limit no harvest regulations were in place. Hurley and Jackson (2002) reported that density increased considerably along with catch rates of black crappie and white crappie in two Nebraska reservoirs after the implementation of a 10 inch minimum length limit. They also noted a decrease in growth, an increase in age structure, and a decline in yield. The regulation was changed to a 9 inch minimum to increase yield. Miller et al. (1990) found decreased growth in age 2 and age 3 black crappie associated with an increase in black crappie density in Lake Okeechobee Florida that resulted from the cessation of commercial fishing. Slow growth in crappie populations can sometimes be attributed to increased density resulting from a single very strong year class. Hanson et al. (1983) observed a 9% reduction in length at age of a very dense year class in a small northern Wisconsin lake.

Managing Growth

In general, it seems that increasing prey density by stocking prey for crappies has had mixed success (Mosher 1984; Devries and Stein 1990) although Allen et al. (1998) suggest that zooplankton density can act to influence growth and density. In some instances, it may be appropriate to stock forage if there is evidence that forage is scarce and crappie condition or growth is poor. Although the link between available forage is intuitive, it appears to be somewhat weak and case dependent. Therefore, given the costs associated with stocking forage and concerns related to disease and ecosystem effects, stocking of forage should generally not be pursued except in very rare circumstances where the need for forage is well documented.

Predators influence crappie growth through reductions in crappie population density. Crappie predators such as largemouth bass (Gabelhouse 1984, Guy and Willis 1995), walleye (McInerny and Cross 2008), saugeye (Galinat et al. 2002), and occasionally northern pike (Willis et al. 1984) have positively influenced crappie growth through reduced crappie population density. Stocking of such predators to increase predator density and predation on black crappies may be a useful tool to increase crappie growth in instances where growth is slow and population densities are high. Muskellunge do not appear to control crappie abundance (Knapp et al. 2008).

Crappie growth appears to be strongly linked to macrophyte density. Both Edwards et al. (1982) and Valley et al. (2004) suggest that both high and low macrophyte densities negatively affect black crappie growth. In situations where crappie growth is slow, harvesting of aquatic vegetation or encouraging growth of native aquatic vegetation in order to achieve 20-80% coverage may result in positive responses in crappie growth.

High levels of exploitation reduce densities and increase crappie growth (Miller et al. 1990; Hurley and Jackson 2002), but modest changes in density may have little or no detectable affect on growth (Hale et al. 1999). Since exploitation can affect crappie growth, restrictive regulations that act to substantially reduce exploitation should only be used in situations where reduced growth is an acceptable outcome.

In populations where growth and size structure have been severely reduced, mechanical removal may be an effective technique to reduce density and improve growth. Hanson et al. (1983) performed an intensive selective removal of 57,000 black crappie between 120-147 mm in length from 50 acre English Lake in Wisconsin (1,140 removed per acre). Approximately 90% of all fish removed were from the same year class of age four fish. Growth rate of this year class and all others present in the lake increased following the mechanical removal. This study provides a case history of a successful mechanical removal effort but a significant amount of gear and time was needed, meaning this type of effort will not be feasible in most circumstances.

Mortality

Abiotic Factors Affecting Mortality

Crappie species support a popular, harvest-oriented sport fishery in Wisconsin. On a regional scale, crappie numbers have been declining. Beard and Kampa (1999) evaluated changes in harvest through time in Wisconsin and found a significant reduction between 1980 and 1991. Grant et al. (2004) found a decrease in crappie CPUE by gill nets in Minnesota lakes between 1983 and 1997. Seasonally, catch rates for crappie by anglers has been shown to peak in late June or early July (Lux and Smith 1960).

Yield produced under different management regimes varies and depends on other characteristics of the population such as natural mortality rates. Allen and Miranda (1995) suggest that the efficacy of length limit regulations depend on natural mortality and growth. In circumstances with high natural mortality, above 30-40%, yield would not be increased with a minimum length limit. Conditional natural mortality rates of this magnitude are common and probably exist in most crappie fisheries. Ellison (1984) estimated annual mortality rates of black crappie to be 59%, 84%, and 100% at ages 2, 3, and 4 respectively in a turbid Nebraska impoundment with negligible harvest. If growth is rapid and natural mortality is low, Allen and Miranda (1995) suggest that yield and average weight of fish can be increased with an 8 inch minimum or 10 inch minimum length limit. Similarly, Hurley and Jackson (2002) reported that density increased considerably along with catch rates of black crappie and white crappie in two Nebraska reservoirs after the implementation of a 10 inch minimum length limit, but they also noted a decrease in yield. In an effort to increase yield Hurly and Jackson (2002) noted that the regulation was changed to a 9 inch minimum. Hale et al. (1999) also found a sizeable decrease in yield with the institution of a 10 inch minimum length limit. Bister et al. 2002 evaluated the implementation of a 9 inch minimum length limit on a South Dakota Lake where the crappie population had been exhibiting undesirable size structure. The 9 inch minimum length limit did not lead to an increase in the number of 9 inch fish in the lake and decreased angler harvest. The poor body condition of large crappie in this lake suggested to the authors that prey resources were not adequate to allow fast growth rates which limited the effectiveness of the minimum length limit. Webb and Ott (1991) examined the effects of a 10 inch minimum length limit in combination with a daily bag limit of 25 in three reservoirs in Texas. Following the 10 inch minimum length limit, RSD-P and yield increased in two Texas reservoirs where growth overfishing was occurring whereas RSD-P did not change and yield increased in a reservoir not experiencing growth overfishing. Angling pressure was low. Willis et al. (1994) noted a sharp decline in size structure of black crappie (From PSD=71-100 reduced to PSD=10) in a 44 acre South Dakota impoundment following a large increase in fishing pressure and harvest (from 1-14 fish per acre to 49 fish per acre). The authors conclude that excessive harvest of larger fish was not a misuse of the resource because natural mortality rates of these fish were likely to be high. However, the resulting crappie population following this high level of harvest would be considered unacceptable to most anglers (PSD=10).

Exploitation of crappie populations also varies substantially among populations and has varying effects. Larson et al. (1991) examined survival and exploitation of black crappie populations in three reservoirs in Georgia. Black crappie exploitation was high, ranging from 40-68%, and annual survival was 8-18%. Larson et al. (1991) concluded that annual survival was low and was not directly related to exploitation rates since there was no obvious pattern of decreasing survival in the presence of increasing exploitation. Therefore, the authors suggested that additional restrictions on harvest would only act to reduce harvest with no benefit to the crappie populations. Colvin (1991a) suggested that high exploitation rates in four Missouri reservoirs may have resulted in size structure that was not satisfactory and also suggested that minimum length limits may remedy this situation. Similarly, Colvin (1991b) investigated the effects of a number of restrictive harvest regulations including a daily bag limit of ten and a 10 inch minimum length limit using field data and an equilibrium yield per recruit model. Colvin (1991b) concluded that restrictive regulations can increase yield and harvested length when growth is maintained and few older fish are present. Parsons and Reed (1998) documented harvest rates of black crappie in excess of 0.5 fish per hour in four Minnesota lakes with low density populations of fast growth rates. Through a tag return survey they were able to estimate annual exploitation of black crappie to be between 7 - 34% but eight of 12 observations fell between 20 - 28%. Total annual mortality of black crappie among the four study lakes was found to be between 48 - 66%. Variation in exploitation and mortality estimates in this study are likely the result of variability in angler effort and the relatively high degree of emigration from the lakes included in this study. Parsons and

Reed (1998) concluded that a reduction in the daily bag limit of crappie from 15 to ten would result in an 18% decrease in harvest on one of four studied lakes but would have no considerable effect on three lakes. Miller et al. (1990) documented a dramatic increase in black crappie densities with the cessation of commercial fishing in Lake Okeechobee Florida. Annual mortality was decreased from 65% to 39%. Maceina et al. (1998) documented an annual exploitation of 33% in an Alabama lake. Reed and Davies (1991) recommended that harvest restrictions not be imposed on an Alabama reservoir because annual mortality was high (73%) but fishing mortality accounted for only 20% of the total mortality. Beard and Kampa (1999) analyzed data from a large set of Wisconsin lakes and found no significant trends in catch or harvest rates of black crappie per hour of angling between 1980 and 1991. Miranda and Dorr (2000) documented that anglers are highly size selective with removals being concentrated on “intermediate age classes” with lower relative harvest on younger and older crappies and concluded that population dynamics and fisheries can be negatively affected when exploitation rates are high. Beard and Kampa (1999) found mean length of black crappie harvested increased over an 11 year period, suggesting an angler preference for larger fish when they are available. Allen and Miranda (2000) used an age structured simulation model to suggest that length limits of 8 inches, 10 inches, and 12 inches could reduce the inter-annual variability in adult densities in waterbodies where recruitment was not highly variable.

There appear to have been few direct examinations of hooking mortality in crappie populations. Muoneke (1992) estimated hooking mortality of approximately 10% in a Texas reservoir in water temperatures ranging from 19-31º C. Hale et al. (1999)

suggested the lack of positive changes in age and size structure that were management goals of a 10 inch minimum length limit in an Ohio reservoir was attributable to a combination of high natural mortality and hooking mortality although no direct evidence of the role of hooking mortality was provided.

Biotic Factors Affecting Mortality

Natural mortality plays a large role in dictating the success or failure of angling regulations with respect to yield. Parsons and Reed (1998) estimated natural mortality rates of 33-40% in four Minnesota Lakes. Populations with low natural mortality, generally classified as 30-35%, and moderate to fast growth benefit most from restrictive length limits. Crappie populations with high natural mortality generally exhibit declines in yield with increasing restrictions on harvest. Bister and Willis (2002) found that a 9 inch minimum length limit on Lake Alvin, SD did not positively affect the age and size structure of the white crappie and black crappie populations although the implementation of the length limit was associated with higher trap net catch per effort. They attributed failure of the regulation to increase growth and size structure on elevated natural mortality and limited prey availability. Hale et al. (1999) suggested the lack of positive changes in age and size structure associated with a 10 inch minimum length limit in an Ohio reservoir was attributable to a combination of high natural mortality and hooking mortality. Maceina et al. (1998) found potential benefits to black crappie and white crappie fisheries associated with a 10 inch minimum length limit in an Alabama lake with above average growth. A Beverton-Holt equilibrium yield model indicated that higher yield would only be achieved if conditional natural mortality was less than 35% which appears to be the case in this lake. However, the number of fish harvested would be reduced. Estimates of annual mortality ranged from 51% to 64%. Isermann et al. (2002b) used a simulation model to examine the effects of 10 inch, 9 inch, and 6 inch minimum length limits on crappie populations in 12 reservoirs in Tennessee. Results differed by reservoir but in general size limits were effective in balancing the tradeoff between yield and size structure only when growth was fast (reaching 10 inches in less than three years) and conditional natural mortality was low (less than 30%). In other cases, the number of larger crappies increased in the presence of length limits but number harvested and yield declined.

Predation contributes substantially to natural mortality rates so changes in densities of predator populations can affect crappie natural mortality rates. McHugh (1990) examined the response of bluegill, white crappie, and black crappie populations to a reduction in largemouth bass density achieved through electrofishing and the use of rotenone in two Alabama impoundments. After a substantial reduction in largemouth bass density, crappie populations increased to the point that they supported recreational fisheries. Gabelhouse (1984) found that proportional stock density (PSD) scores for both black crappie and white crappie were inversely proportional to largemouth bass PSD, and suggested that higher densities of largemouth bass less than 15 inches can reduce crappie densities through intraspecific competition allowing crappies to attain larger sizes. Galinat et al. (2002) suggested that saugeye predation on black crappie in a lake in Minnesota reduced abundance and intraspecific competition of small black crappie which resulted in increased growth and improved size structure of the remaining black crappies.

Neal et al. (1999) found that black crappie total length and relative weight increased as a result of predation from stocked hybrid striped bass. Finally, Willis et al. (1984) suggested that northern pike predation was a factor in maintaining desirable black crappie size structure in a small impoundment in Colorado.

Declines in suitable habitat for crappies will result in increased mortality. Suitable black crappie habitat includes clear to slightly turbid water with various substrate types (Becker 1983). The most important habitat requirement for crappies is aquatic macrophyte abundance in the range of 20-80% (Becker 1983; Edwards et al. 1982; Valley et al. 2004). For example, Bettoli et al. 1993 documented a reduction in density and biomass of black crappie when aquatic vegetation was eliminated by grass carp *(Ctenopharyngodon idella)* in a Texas reservoir. Prior to the introduction of grass carp, aquatic macrophytes existed in approximately 45% of the reservoir. Water turbidity and thermal habitat should also be considered to be important components of crappie habitat. Ellison (1984) identified a likely interaction between water temperature and turbidity that affected mortality of black crappie. In the turbid Nebraskan impoundment examined in this study black crappie were unable to switch to fish prey and continued to consume zooplankton despite high energetic costs associated with their capture. At high temperatures this foraging strategy did not appear to be viable and total annual mortality of age 4 black crappie was estimated to be 100%.

Managing Mortality

The amount of natural mortality occurring in crappie populations is a key parameter influencing the efficacy of management actions that act to restrict harvest. In general, modeling results and field investigations suggest that high rates of natural mortality, above approximately 35%, generally cause a reduction in yield when minimum length limits are instituted. Natural mortality rates are generally beyond the control of management agencies but rates could be artificially increased through the stocking of predator species or artificially reduced through increased harvest of predators.

Management of aquatic macrophytes in order to obtain 20-80% coverage may aid in efforts to minimize natural mortality.

Yield is affected by angling regulations. Minimum length limits can increase yield in situations where natural mortality and growth is rapid and in situations where growth overfishing is occurring (Webb and Ott 1991; Allen and Miranda 1995). Minimum length limits also generally increase crappie densities but can reduce overall yield (Hurley and Jackson 2002; Hale et al. 1999). Minimum length limits are more likely to increase crappie densities and are therefore more likely to be successful if this is the stated management objective. Minimum length limits should only be considered in instances when moderate to fast growth rate of crappie has been shown. Natural and fishing mortality rates should be examined prior to implementing minimum length limits if the management goal is to increase yield.

Crappie populations can sustain relatively high exploitation rates (Larson et al. 1991; Reed and Davis 1991). However, high exploitation rates may result in population size structures that are not desirable (Colvin 1991a). If exploitation rates are high and population size structure is not desirable, restrictions on exploitation through the use of minimum length limits could be considered. However, Isermann and Carlson (2009) evaluated the effectiveness of 9, 10, and 11 inch minimum length limits on four Minnesota lakes. Over 40% of black crappie among the four lakes became protected but all three versions of minimum length limits were largely unsuccessful at improving size structure. Rates of illegal harvest were high in this study (in one lake 87% of harvested fish were sub-legal) which may have been a factor prohibiting effectiveness of the regulations. This case study also suggests that compliance with minimum length limits for crappie may be poor, and the authors stress the need for public awareness. Reducing bag limits to moderate levels (10-15 fish daily) generally does not seem to substantially affect yield, because few anglers achieve daily bag limits. Severe reductions in daily bag (e.g. to five fish daily) may have more effectiveness, particularly in highly exploited populations, but are likely to be unpopular with anglers. Hooking mortality should be included in exploitation calculations if possible when considering whether exploitation is excessive.

References

Allen, M. S., and L. E. Miranda. 1995. An evaluation of the value of harvest restrictions in managing crappie fisheries. North American Journal of Fisheries Management 15: 766-772.

Allen, M. S., and L. E. Miranda. 1998. An age structured model for erratic crappie fisheries. Ecological Modelling 107:289–303.

Allen, M. S., M. V. Hoyer, and D. E. Canfield, Jr. 1998. Factors related to black crappie occurrence, density, and growth in Florida lakes. North American Journal of Fisheries Management 18: 864-871.

Beam, J. H. 1983. The effect of annual water level management on population trends of white crappie in Elk City Reservoir, Kansas. North American Journal of Fisheries Management 3: 34-40.

Beard, T. D., Jr., and J. M. Kampa. 1999. Changes in bluegill, black crappie, and yellow perch populations in Wisconsin during 1967-1991. North American Journal of Fisheries Management 19:1037-1043.

Becker, G. C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison.

Bister, T. J., and D. W. Willis. 2002. Evaluation of a 23-cm minimum length limit for black and white crappies in a small South Dakota impoundment. North American Journal of Fisheries Management 22: 1364-1368.

P. W. Bettoli, M. J. Maceina, R. L. Noble. 1993. Response of a Reservoir Fish Community to Aquatic Vegetation Removal. North American Journal of Fisheries Management 13: 110-124.

Bister, T. J., D. W. Willis, A. D. Knapp, and Todd R. St. Sauver. 2002. Evaluation of a 23-cm minimum length limit for black and white crappies in a small South Dakota impoundment. North American Journal of Fisheries Management 22:1364-1368.

Bunnell, D. B., M. J. González, and R. A. Stein. 2003. Zooplankton biomass enhances growth, but not survival, of first-feeding *Pomoxis* spp. Larvae. Can. J. Fish. Aquat. Sci. 60: 1314–1323.

Bunnell, D. B., R. S. Hale, M. J. Vanni, and R. A. Stein. 2006. Predicting crappie recruitment in Ohio reservoirs with spawning stock size, larval density, and chlorophyll concentrations. North American Journal of Fisheries Management 26: 1-12.

Carline, R. F., B. L. Johnson, and T. J. Hall. 1984. Estimation and interpretation of proportional stock density for fish populations in Ohio impoundments. North American Journal of Fisheries Management 4:139-154.

Colvin, M. A. 1991a. Population characteristics and angler harvest of white crappies in four large Missouri reservoirs. North American Journal of Fisheries Management 11: 572-584.

Colvin, M. A. 1991b. Evaluation of minimum-size limits and reduced limits on the crappie populations and fisheries in five large Missouri reservoirs. North American Journal of Fisheries Management 11: 585-597.

Devries, D. R. and R. A. Stein. 1990. Manipulating shad to enhance sport fisheries in North America: and assessment. North American Journal of Fisheries Management 13: 110-124.

Dubuc, R. A., and D. R. DeVries. 2002. An exploration of factors influencing crappie early life history in three Alabama impoundments. Transactions of the American Fisheries Society 131: 476-491.

Edwards, E.A., D.A. Krieger, M. Bacteller, and O.E. Maughan. 1982. Habitat suitability index models: black crappie. U.S. Fish and Wildlife Service Biological Report 82 (10.6). 25 pp.

Ellison, D. G. 1984. Trophic dynamics of a Nebraska black crappie and white crappie population. North American Journal of Fisheries Management 4:355-364.

Epifanio, J. M., M. Hooe, D. H. Buck, and D. P. Philipp. 1999. Reproductive Success and Assortative Mating among *Pomoxis* Species and Their Hybrids. Transactions of the American Fisheries Society 128:104–120.

Gabelhouse, D. W. 1984. An assessment of crappie stocks in small Midwestern private impoundments. North American Journal of Fisheries Management 4: 371-384.

Galinat, G. F., D. W. Willis, B. G. Blackwell, and M. J. Hubers. 2002. Influence of a saugeye (sauger x walleye) introduction program on the black crappie population in Richmond Lake, South Dakota. North American Journal of Fisheries Management 22: 1416-1424.

Grant, G. C., Y. Schwartz, S. Weisberg, and D. H. Schupp. 2004. Trends in abundance and mean size of fish captured in gill nets from Minnesota lakes, 1983-1997. North American Journal of Fisheries Management 24:417-428.

Green, W. C. 1935. The distribution of Wisconsin fishes. pp. 151-153. State of Wisconsin Conservation Commission, Madison.

Guy, C. S. and D. W. Willis. 1995. Population characteristics of black crappies in South Dakota waters: A case for ecosystem-specific management. North American Journal of Fisheries Management 15:754-765.

Hale, R. S. 1999. Growth of white crappies in response to temperature and dissolved oxygen conditions in a Kentucky reservoir. North American Journal of Fisheries Management 19: 591-598.

Hale, R. S., M. E. Lundquist, R. L. Miller, and R. W. Petering. 1999. Evaluation of a 254-mm minimum length limit on crappies in Delaware Reservoir, Ohio. North American Journal of Fisheries Management 19:804–814.

Hanson, D. A. B. J. Belonger, and D. L. Schoenike. 1983. Evaluation of a mechanical population reduction of black crappie and black bullheads in a small Wisconsin lake. North American Journal of Fisheries Management 3:41-47.

Hurley, K. L., and J. J. Jackson. 2002. Evaluation of a 254 mm minimum length limit for crappies in two southeast Nebraska reservoirs. North American Journal of Fisheries Management 22:1369-1375.

Isermann, D. A., W. L. McKibbin, and D. W. Willis. 2002a. An analysis of methods for quantifying crappie recruitment variability. North American Journal of Fisheries Management 22:1124-1135.

Isermann, D. A., S. M. Sammons, and P. W. Bettoli. 2002b. Predictive evaluation of size restrictions as management strategies for Tennessee Reservoir crappie fisheries. North American Journal of Fisheries Management 22:1349-1357.

Isermann, D. A., and A. J. Carlson. 2009. Can minimum length limits improve size structure in Minnesota black crappie populations? Minnesota Department of Natural Resources Investigational Report 552.

Isermann, D. A. 2010. Validation of nonlethal sex determination for black crappies during spring. North American Journal of Fisheries Management 30:352–353.

Isermann, D. A., A. L. Thompson, and P. J. Talmage. 2010. Comparisons of sex-specific growth and weight-length relationships in Minnesota black crappie populations. North American Journal of Fisheries Management 30:354-360

Jackson, J. J., and K. L. Hurley. 2005. Relative growth of white crappie and black crappie in the United States. Journal of Freshwater Ecology 20:461-467.

Keast, A. 1968. Feeding biology of the black crappie, *Pomoxis nigromaculatus*. Journal of the Fisheries Research Board of Canada 25:285-297.

Knapp, M. L., S. W. Mero, D. J. Bohlander, and D. F. Staples. 2008. Fish Community Responses to the Introduction of Muskellunge in Minnesota Lakes. Minnesota Department of Natural Resources Special Publication 166.

Knights, B. C., B. L. Johnson, and M. B. Sandheinrich. 1995. Responses of bluegills and black crappies to dissolved oxygen, temperature, and current in backwater lakes of the Upper Mississippi River during winter. North American Journal of Fisheries Management 15:390-399.

Larson, S. C., B. Saul, and S. Schleiger. 1991. Exploitation and survival of black crappies in three Georgia reservoirs. North American Journal of Fisheries Management 11: 604-613.

Lyons, J., K. M. Schoephoester, J. Griffin, J. M. Stewart, and D. Fago. 2012. Wisconsin Department of Natural Resources and Wisconsin Aquatic Gap Mapping Application http://infotrek.er.usgs.gov/fishmap.

Lux, F. E., and L. L Smith Jr. 1960. Some Factors Influencing Seasonal Changes in Angler Catch in a Minnesota Lake. Transactions of the American Fisheries Society, 89:67-79.

Maceina, M. J., D. R. Bayne, A. Scott Hendricks, W. C. Reeves, W. P. Black, and V. J. Dicenzo. 1996. Compatibility between water clarity and black bass and crappie fisheries in Alabama. Pages 296–305 *in* L.E. Miranda and D. R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society, Symposium 16, Bethesda, Maryland.

Maceina, M. J., O. Ozen, and M. S. Allen. 1998. Use of equilibrium yield models to evaluate length limits for crappies in Weiss Lake, Alabama. North American Journal of Fisheries Management 18: 854-863.

Maceina, M. J. and M. R. Stimpert. 1998. Relations between reservoir hydrology and crappie recruitment in Alabama. North American Journal of Fisheries Management 18: 104-113

Maceina,. M. J. 2003. Verification of the influence of hydrologic factors on crappie recruitment in Alabama reservoirs. North American Journal of Fisheries Management 23: 470-480.

McHugh, J. J. 1990. Responses of bluegills and crappies to reduced abundance of largemouth bass in two Alabama impoundments. North American Journal of Fisheries Management 10: 344-351.

McInerny, M. C., and T. K. Cross. 1999. Effects of lake productivity, climate warming, and intraspecific density on growth and growth patterns of black crappie in southern Minnesota lakes. Journal of Freshwater Ecology 14: 255-264.

McInerny, M. C., and T. K. Cross. 2008. Length at age estimates of black crappie among lake classes, reservoirs, impoundments, and rivers in Minnesota. Minnesota Department of Natural Resources Investigational Report 551.

McKeown, P. E., and S. R. Mooradian. 2002. Factors influencing recruitment of crappies in Chautauqua Lake, New York. North American Journal of Fisheries Management 22:1385-1392.

Miller, S. J., D. D. Fox, L. A. Bull, and T. D. McCall. 1990. Population dynamics of black crappie in Lake Okeechobee, Florida, following suspension of commercial harvest. North American Journal of Fisheries Management 19:98-105.

Miller, L. M., M. C. McInerny, and J. Roloff. 2008. Crappie hybridization in southern Minnesota lakes and its effects on growth estimates. North American Journal of Fisheries Management 28:1120–1131.

Miranda, L. E., and B. S. Dorr. 2000. Size selectivity of crappie angling. North American Journal of Fisheries Management 20:706-710.

Miranda, L. E., and M. S. Allen. 2000. Use of length limits to reduce variability in crappie fisheries. North American Journal of Fisheries Management 20:752-758.

Mosher, T. D. 1984. Responses of white crappie and black crappie to threadfin shad introductions in a lake containing gizzard shad. North American Journal of Fisheries Management 4:365-370.

Muoneke, M. L. 1992. Hooking mortality of white crappie, *Pomoxis annularis* Rafinesque, and spotted bass, *Micropterus punctulatus* (Rafinesque), in Texas reservoirs. Aquaculture Research 23:87-93.

Neal, J. W., R. L. Noble, and J. A. Rice. 1999. Fish community response to hybrid striped bass introduction in warmwater impoundments. North American Journal of Fisheries Management 19:1044-1053.

Parsons, B. G., and J. R. Reed. 1998. Angler exploitation of bluegill and black crappie in four west-central Minnesota lakes. Minnesota Department of Natural Resources Investigational Report 468.

Parsons, B. G., J. R. Reed, H. G. Fullhart, and V. A. Snook. 2004. Factors affecting black crappie recruitment in four west-central Minnesota lakes. Minnesota Department of Natural Resources Investigational Report 514.

Parsons, B. G., and J. R. Reed. 2005. Movement of black crappies and bluegills among interconnected lakes in Minnesota. North American Journal of Fisheries Management 25:689-695.

Phelps, Q. E., A. M. Lohmeyer, N. C. Wahl, J. M. Zeiler, and G. W. Whitledge. 2009. Habitat characteristics of black crappie nest sites in an Illinois impoundment. North American Journal of Fisheries Management 29:189-195.

Pine, W. E. III, and M. S. Allen. 2001. Differential growth and survival of weekly age-0 black crappie cohorts in a Florida Lake. Transactions of the American Fisheries Society 130: 80-91.

Pope, K.L. 1996. Factors affecting recruitment of black crappies in South Dakota waters. Doctoral dissertation. Brookings: South Dakota State University.

Pope, K. L., and D. W. Willis. 1997. Environmental characteristics of black crappie (*Pomoxis nigromaculatus*) nesting sites in two South Dakota waters. Ecology of Freshwater Fish 6:183-189.

Pope, K. L., and D. W. Willis. 1998. Early life history and recruitment of black crappie (*Pomoxis nigromaculatus*) in two South Dakota waters. Ecology of Freshwater Fish 7:56-68.

Reed, J. R., and W. D. Davies. 1991. Population dynamics of black crappies and white crappies in Weiss Reservoir, Alabama: Implications for the implementation of harvest restrictions. North American Journal of Fisheries Management 11:598-603.

Sammons, S. M. and P. W. Bettoli. 2000. Population dynamics of a reservoir sport fish community in response to hydrology. North American Journal of Fisheries Management 20: 791-800.

Sammons, S. M., D. A. Isermann, and P. W. Bettoli. 2002. Variation in Population Characteristics and Gear Selection between Black and White Crappies in Tennessee Reservoirs: Potential Effects on Management Decisions. North American Journal of Fisheries Management 22:863–869.

Schneberger, F. 1972. The black crappie: its life history, ecology and management. Wisconsin Department of Natural Resources. Publication 243-72, Madison

Schneider, J. C. 2000. Evaluation of the effects of the herbicide sonar on sport fish populations in Michigan Lakes. Michigan Department of Natural Resources Fisheries Technical Report 2000-2.

Seaburg, K. G. and J. B. Moyle. 1964. Feeding habits, digestive rates, and growth of some Minnesota warmwater fishes. Transactions of the American Fisheries Society 93:269-285.

St. John, T. R. and W. P. Black. 2004 Methods for predicting age-0 crappie year-class strength in J. Percy Priest Reservoir, Tennessee. North American Journal of Fisheries Management 24:1300–1308.

Valley, R. D., T. K. Cross, and P. Radomski. 2004. The role of submersed aquatic vegetation as habitat for fish in Minnesota lakes, including the implications of non-native plant invasions. Minnesota Department of Natural Resources Special Publication 160.

Webb, M. A., and R. A. Ott, Jr. 1991. Effects of length and bag limits on population structure and harvest of white crappies in three Texas reservoirs. North American Journal of Fisheries Management 11: 614-622.

Willis, D. W., Smeltzer, J. F., and S. A. Flickinger. 1984. Characteristics of a crappie population in an unfished small impoundment containing northern pike. North American Journal of Fisheries Management 4: 385-389.

Willis, D. W., R. M. Neumann, and C. S. Guy. 1994. Influence of angler exploitation on black crappie population structure in a rural South Dakota impoundment. Journal of Freshwater Ecology 9:153-158.

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