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Abstract

White Bass (*Morone chrysops*) and Hybrid Striped Bass (*M. saxatillis* × *M. chrysops*) populations often coexist in the same waterbody and are known to achieve different lengths, have differing reproductive success, and provide different opportunities for anglers. However, comparative population dynamics from systems where Moronids are managed with the same regulation is often lacking. This study aimed to assess the recruitment, mortality, and growth of these species from seasonal samples collected at Lake McConaughy in 2015 and fall 2016. White Bass demonstrated highly variable recruitment in Lake McConaughy despite stocking efforts (mean recruitment variability index = 0.157). Hybrid Striped Bass year class strength was also variable, but RVI was not calculated as the number of missing year classes exceed the number of present year classes. Total annual mortality estimates for Hybrid Striped Bass (39.7%) and White Bass (41.4%) were consistent with values reported in other populations, but both species were observed to achieve uncommon longevity. Both species exhibited sexual size dimorphism, and growth was moderate and consistent with average values presented for North American populations. This study provides insight into the population dynamics of two species with trophy potential managed by the same regulation in Lake McConaughy. Differences in growth patterns indicate the current regulation affects each species differently, and managers may be able to utilize this to inform decisions about management of coexisting Moronid populations.

Keywords: White Bass, Hybrid Striped Bass, Growth, Mortality, Recruitment

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Introduction

Moronidae represents a popular and common sportfish family throughout much of the United States. Popular fisheries often develop on waterbodies with harvestable or trophy populations of White Bass (*Morone chrysops*) and Hybrid Striped Bass (*M. saxatillis* × *M. chrysops*). White Bass are among the most commonly sought and harvested sportfish in many large reservoirs (Bauer 2002, Colvin 2002a, Ganus *et al*. 2015, Lincoln *et al*. 2016). Additionally, Hybrid Striped Bass have been introduced in numerous locations to create unique trophy fisheries due to their propensity for fast growth, aggressive behavior, and fighting ability (Schultz *et al*. 2013a). However, both species tend to receive less research and management attention than many other sportfish species (Guy *et al*. 2002, Schultz *et al*. 2013b).

Fish populations are regulated by three primary factors: recruitment, growth, and mortality. Establishing a baseline of population dynamics data is important for ongoing management and research purposes. Recruitment is the most variable of these dynamic rate functions (Ricker 1975) and is often erratic in large reservoirs for Moronidae species (Colvin 2002a). Erratic recruitment may result in variable catch and harvest rates (Colvin 1991, Willis *et al*. 2002), causing managers to implement stocking protocols to supplement populations. Conversely, lower densities, as a result of erratic recruitment, can also create fast growth and highly productive fisheries (Isermann *et al*. 2005, Schoenebeck and Brown 2011). White Bass have demonstrated erratic recruitment in Nebraska waters (Bauer 2002, DeBoer *et al*. 2013). Hybrid Striped Bass populations are controlled by stocking, as populations do not naturally recruit successfully in the state (Lueckenhoff 2011). Previous genetic analysis has demonstrated a low incidence (<1%) of back-crossing with existing White Bass populations from samples taken at multiple Nebraska reservoirs (Lueckenhoff 2011). Therefore, elucidating patterns of recruitment within a waterbody can guide decisions on stocking and harvest regulations.

Growth and mortality are important to monitor for potential changes in population structure, community interaction, and angler use. Growth rates can be influenced by numerous factors including prey availability (Shoup *et al*. 2007), habitat quality and availability (Sammons and Bettoli 2000), season (Pope and Willis 1996), temperature and growing degree days (Uphoff *et al*. 2013), and geographic region (Schultz *et al*. 2013a). Sexual size dimorphism (SSD) has also been suggested to influence growth in White Bass (Guy *et al*. 2002), but little information exists about SSD in Hybrid Striped Bass populations. Mortality has been considered the most important dynamic rate function to understand for making management decisions (Quist *et al*. 2004). Monitoring mortality over time can be important for identifying changes in species interactions, environmental conditions, or exploitation (Quist *et al*. 2004, Schultz *et al*. 2013b). Accurate mortality estimates are necessary to effectively manage populations, including understanding growth potential, guiding stocking decisions, and evaluating harvest impacts, but are difficult to ascertain when recruitment is erratic (Willis *et al*. 2002, Isermann *et al*. 2005).

Management of coexisting Moronid populations can be difficult. Moronid hybrids tend to be reproductively viable (Avise and Van Den Avyle 1984, Forshage *et al*. 1986, Storey *et al*. 2000), which may lead to back-crossing. Although genetic crossing does not appear to be an issue for Hybrid Striped Bass and White Bass in Nebraska (Lueckenhoff 2011), identification remains an issue. Difficulties identifying Hybrid Striped Bass from White Bass have been documented for anglers and biologists (Williams 1976, Storey *et al*. 2000, Lueckenhoff 2011), complicating population assessments, creel surveys, and management. To alleviate identification concerns where these species coexist, Hybrid Striped Bass and White Bass are managed under an aggregate regulation of a 15 fish daily bag limit with one over 16 inches (406 mm) in Nebraska. However, population dynamics summaries of these species are limited in areas where they coexist and are managed under the same regulation. Therefore, this study aimed to assess the dynamics of coexisting and co-managed Hybrid Striped Bass and White Bass populations in Lake McConaughy, Nebraska. The objectives of this study were to 1.) assess age structure and age at maturity, 2.) index recruitment, 3.) estimate mortality, and 4.) estimate sex-specific growth of Hybrid Striped Bass and White Bass in Lake McConaughy during 2015 and 2016.

Study Site

Lake McConaughy has consistently supported high-quality Moronid fisheries. Originally constructed for irrigation and flood control purposes, Lake McConaughy is the largest reservoir in Nebraska and has a mean depth of 22 m, a maximum depth of 53 m, and extends approximately 35 km (Taylor and Hams 1981). Historically, White Bass have been among the most commonly sought and harvested species in Lake McConaughy since constructions was completed in the early 1940s (McCarraher *et al*. 1971, Porath *et al*. 2003) and were the third most commonly sought species in Lake McConaughy in the late from 2009-2013 (Chizinski *et al.* 2013). Additional Moronid populations have been developed in Lake McConaughy to produce trophy fishing opportunities, including a popular Striped Bass *Morone saxatilis* fishery persistent from the late 1960s to the 1980s (McCarraher *et al*. 1971). Striped Bass stockings were canceled in the late 1970s following the collapse of the Gizzard Shad *Dorosoma cepedianum* and Rainbow Trout *Oncorhynchus mykiss* populations, which coincided with increasing Striped Bass numbers in Lake McConaughy (Darrol Eichner, personal communication). Hybrid Striped Bass were first introduced in 1992 following unsuccessful efforts to reestablish Rainbow Trout in order to provide a unique fishery that could be better controlled by stocking. Hybrid Striped Bass have been supplementally stocked every other year and were the fifth most commonly sought species in Lake McConaughy from 2009-2013 (Chizinski *et al.* 2013). Concerns about a decline in White Bass abundance have led the Nebraska Game and Parks Commission (NGPC) to supplementally stock White Bass in 2000-2008 and in 2014-2016. However, no information on the contribution of stocked White Bass to the population is available for year classes prior to 2015 and present results indicate that stocked White Bass comprised a low percentage of the 2015 year class (Perrion 2016).

Material and Methods

Fish Collection

We collected fish during spring (May), summer (July), and fall (September) in 2015 and fall in 2016 using standard NGPC monofilament gill nets measuring 45.7 m long and 1.8 m deep (Zuerlein and Taylor 1985). We set gill nets, composed of six 7.6 m long panels with bar mesh sizes of 19.1, 25.4, 31.8, 38.1, 50.8 and 76.2 mm, perpendicular to shore with the shallow, small mesh end set at a depth of 2-3 m. We set a total of 36 gill nets overnight in randomized locations throughout the reservoir during each season.

Age and Recruitment

Age and growth parameters were collected and analyzed for both species. We measured (TL; mm) all fish captured and determined sex and maturity by observation of gonads on all fish sacrificed for aging (*n*=125 Hybrid Striped Bass and 293 White Bass). We collected sagittal otoliths, the recommended aging structure for White Bass (Soupir *et al*. 1997), from both species on up to 10 individuals per cm length class in all three seasons during 2015 and 5 per cm class in fall 2016. We cleaned the otoliths and allowed to dry for at least one week. After drying, we mounted the otoliths in epoxy, transversely sectioned (0.3 mm), sanded, and placed them in immersion oil. We captured images at 40× magnification using a Canon EOS Rebel T6i camera mounted to a Motic BA410E compound microscope. Two readers independently aged each otolith, and any structure with disagreement in age was read in concert until a consensus age was agreed upon (Quist *et al*. 2012).

Fall age frequency data was used to assess recruitment of White Bass. We developed an age-length key for both species using a semi-random age assignment within the FSA package in Program R (Ogle 2018). We quantified recruitment using the recruitment variability index (RVI), which was calculated from the fall age frequency data using the following equation:

$$\mathrm{RVI} = \left(\frac{\mathrm{CRF}}{\mathrm{N_M} - \mathrm{N_P}}\right) - \frac{\mathrm{N_M}}{\mathrm{N_P}}$$

where CRF is the total cumulative relative frequency for all age classes included in analysis, N_M is the number of missing year classes in the sample, and N_P is the total number of year classes present in the sample. The RVI can only be calculated for samples where $N_P > N_M$, and values can range from -1.0 to 1.0, with higher values representing consistent recruitment (Guy and Willis 1995). Calculation of the RVI was limited to fall samples for White Bass since Hybrid Striped Bass recruitment is solely limited by stocking success, and $N_P < N_M$ for spring and summer White Bass catch. We used ages 1-10 and 1-11 in White Bass RVI analysis during fall 2015 and 2016, respectively, as White Bass were fully recruited to the gill nets in the fall at age 1. We calculated a mean RVI value using data from both sampling years to improve index effectiveness (Quist 2007).

Mortality

We combined the fall age-length key frequency data from 2015 and 2016 to assess mortality. We estimated total annual mortality for each species using weighted catch curves and used the equation $\log_e$(age-length key frequency + 1) to account for missing year classes. Combining age frequency data from multiple years reduces the impact of recruitment variability (Miranda and Bettoli 2007).

We estimated back-calculated length at age data from measurements of otolith sections. Since back-calculated data were being used, we utilized length at age data from otoliths collected in all three seasons in 2015 and in fall 2016. We measured aging structures at each annulus using the otolith image and the iSolution Lite software. We estimated back-calculated lengths using the Dahl-Lee direct proportion method for the three most recent annuli measurements to avoid the influence of Lee's phenomenon (Erickson 1983, Quist *et al*. 2012). We developed sex-specific growth curves from the back-calculated length at age data using a nonlinear mixed effects model and the von Bertalanffy growth equation:

$$L_t = L_\infty \left[1 - e^{-k(t - t_0)}\right]$$

where L_t is the length at time t, L_∞ is the asymptotic mean length, k is the growth coefficient, and t_0 is the hypothetical time at which length is 0 (Allen and Hightower 2010). When examining back-calculated data, nonlinear mixed-effect modelling is preferred to account for autocorrelation in the back-calculated data (Pinheiro and Bates 2000) while generating parameter estimates at the individual (random effect) and population (fixed effect) levels (Vigliola and Meekan 2009). We then compared sex-specific von Bertalanffy growth parameter estimates using a single factor analysis of variance and an *a priori* significance level of 0.05.

Results

Aging and Recruitment

Hybrid Striped Bass ages ranged from 0-16 in 2015 and 1-9 in 2016 (Table 1). Male Hybrid Striped Bass reached sexual maturity at age 2 and were observed to age 16, while females matured at age 3 and were observed at a maximum age of 14. Hybrid Striped Bass were stocked in 8 of the previous 18 years in Lake McConaughy, and 6 of those stocked year classes were observed (Table 1). Age 4 was the most abundant age class during 2015, and age 1 accounted for more than 75% of the 2016 sample.

The maximum observed White Bass age was 14, with males and females observed to ages 14 and 10 years, respectively. The most frequently collected age class in all sampling seasons was age 1 (Table 1), and the 2005 year class (age 10 in 2015) was commonly encountered in all samples. White Bass were not observed from the 2009 and 2006 year classes, and only one individual was observed from the 2010 and 2007 year classes. Female and male White Bass were observed to be sexually mature at 2 years, although some males were mature at age 1. The

Table 1. Age-length key frequencies for Hybrid Striped Bass and White Bass collected during 2015 and 2016 at Lake McConaughy, Nebraska where *n* is the number of aged individuals in the sample. Asterisks are used to denote years where stocking occurred for each species.

			Age (years)																
Year	Season	*n*	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
			Hybrid Striped Bass																
2015	Spring	32	0*	0	3*	0	65*	0	0	0	16*	0*	0*	0	0	0	17*	0	1*
	Fall	35	13*	0	17*	0	21*	0	0	0	1*	0*	0*	0	0	0	0*	0	0*
2016	Fall	58	0	53*	0	1*	0	14*	0	0	0	1*	0*	0*	0	0	0	0*	0
			White Bass																
2015	Spring	22	0*	10	0	2	2	0	0*	1	0*	0*	7*	0*	0*	0*	0*	0	0
	Summer	61	0*	31	1	1	5	1	0*	1	1*	0*	19*	0*	1*	0*	0*	0	0
	Fall	156	75*	220	3	5	16	0	0*	0	0*	0*	8*	0*	0*	0*	1*	0	0
2016	Fall	54	2*	68*	56	2	1	1	0	0*	0	0*	0*	4*	0*	0*	0*	0*	0

mean RVI value of 0.157 was calculated from the annual values of 0.132 and 0.182 in 2015 and 2016, respectively.

Mortality

A total of 117 Hybrid Striped Bass were aged in fall of both years, and the weighted total annual mortality was estimated at 39.7% (95% CI = 4.7-61.8%; Figure 1). A total of 386 White Bass were aged in the combined fall samples, and weighted total annual mortality of White Bass was estimated at 41.4% (95% CI = 23.8-55.0%; Figure 1).

Growth

The Hybrid Striped Bass community in Lake McConaughy demonstrated trophy potential. Hybrid Striped Bass were observed in the spring up to 755 mm TL, exceeding trophy size (710 mm; Dumont and Neely 2011), but trophy-sized fish were not collected during summer or fall samples. Comparison of von Bertalanffy growth coefficients indicated a difference in L_∞ between sexes (Table 2), with female Hybrid Striped Bass growing larger than males (Figure 2). Von Bertalanffy curves indicated both sexes reached quality (410 mm) length at 3 years, and preferred (510 mm) and memorable (610 mm) lengths were achieved by females at 4 and 7 years, respectively, and by males at 5 and 9 years.

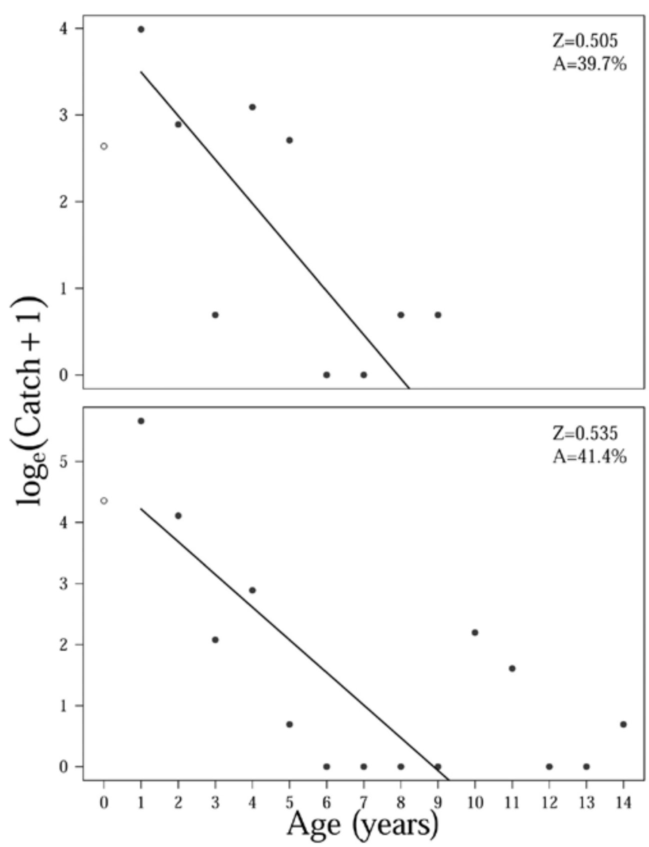

Figure 1. Weighted catch curve of Hybrid Striped Bass (top) and White Bass (bottom) using combined samples from fall 2015 and 2016 collected in Lake McConaughy, Nebraska.

Table 2. Sex-specific von Bertalanffy growth estimates, upper and lower 95% confidence intervals (CI), and analysis of variance test statistics for Hybrid Striped Bass and White Bass collected in Lake McConaughy, Nebraska during 2015 and 2016.

	Male			Female				
Parameter	Estimate	Lower 95 CI	Upper 95 CI	Estimate	Lower 95 CI	Upper 95 CI	*F*	*P*
				Hybrid Striped Bass				
L_∞	636	617	654	679	652	706	200.8	<0.001
K	0.3624	0.3255	0.3993	0.3409	0.3025	0.3793	0.6	0.433
t_0	-0.331	-0.474	-0.188	-0.396	-0.524	-0.268	5.6	0.020
				White Bass				
L_∞	360	352	367	387	378	396	114.2	<0.001
K	0.713	0.611	0.8152	0.775	0.682	0.868	0.8	0.384
t_0	-0.168	-0.331	-0.004	0.047	-0.055	0.148	1627.7	<0.001

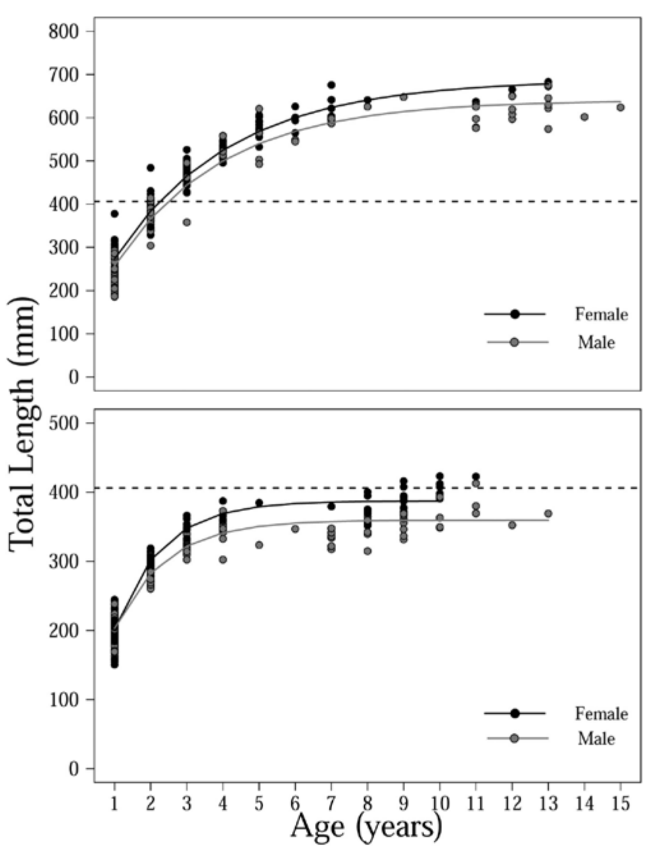

Figure 2. Back-calculated lengths at age and associated von Bertalanffy growth curves for male and female for Hybrid Striped Bass (top) and White Bass (bottom) collected in Lake McConaughy, Nebraska during 2015 and 2016. The dashed lines correspond to the current one over 406 mm regulation.

White Bass grew in length through the first few years before growth asymptotes around age 6. Several memorable size White Bass were collected, particularly in the summer samples, with the largest achieving trophy length of 460 mm. Female White Bass grew faster than males (Figure 2), and differences were observed in L_∞ and t_0 values (Table 2). Length at age estimated from the von Bertalanffy curve indicated females grew rapidly and reached preferred length (300 mm; Gabelhouse 1984) by age 2 and memorable length (380 mm) at age 6. Male White Bass reached quality (230 mm) and preferred lengths at 2 and 3 years, respectively, but L_∞ was below memorable size (Figure 2).

Discussion

Both Hybrid Striped Bass and White Bass exhibited normal maturation schedules but uncommon longevity in Lake McConaughy. White Bass maturity occurred at similar ages to other populations (Colvin 1993, Ganus *et al*. 2015). Although Hybrid Striped Bass were observed to be sexually mature at typical ages (Hodson 1989), natural reproduction and recruitment has never been evaluated or documented in Lake McConaughy. To our knowledge, age 16 is among the oldest recorded Hybrid Striped Bass, and the abundant 14 year old age class also exceeded the maximum ages of 9 and 11 years reported from Hybrid Striped Bass populations in Midwest and southern waterbodies, respectively (Schultz *et al*. 2013a). White Bass have been observed to age 14 in other populations (Willis *et al*. 2002) but typically exhibit maximum ages below 10 years (Forney and Taylor 1963, Phelps *et al*. 2011, Baker and Lochmann 2012, Ganus *et al*. 2015). Although the mechanism for this increased longevity is not well understood, it is hypothesized that fish seek thermal refuges (Moss 1985, Douglas and Jahn 1987, Quist *et al*. 2002) at the greater depths in Lake McConaughy, which could reduce metabolism and mortality. This uncommon longevity has influenced the population dynamics estimates of Lake McConaughy Moronids by reducing mortality and allowing fish to achieve greater lengths, such as the trophy sizes observed in these populations, but the effect on recruitment appears to be limited.

Recruitment was erratic for White Bass, and year class strength was variable for Hybrid Striped Bass in Lake McConaughy. The RVI values were low for White Bass in Lake McConaughy and were below values reported for the Lake Sharpe, South Dakota population (Ahrens *et al*. 2010), so despite supplemental stocking efforts consistent year classes have not been developed. Fluctuation of White Bass year class strength is common (Forney and Taylor 1963, Colvin 2002a, DiCenzo and Duval 2002, Phelps *et al*. 2011). Erratic recruitment in Lake McConaughy may be a result of competitive interaction with Alewife (*Alosa pseudoharengus*), which have been documented to negatively impact zooplankton and fish populations in other waterbodies (Wells 1970, Kohler and Ney 1980, Kohler and Ney 1981, Brandt *et al*. 1987) and are suggested to cause variable White Bass recruitment in multiple Nebraska waters (Bauer 2002). Other factors, such as reservoir inflow (DiCenzo and Duval 2002), can impact White Bass recruitment and may play a role in Lake McConaughy. Efforts to stock Hybrid Striped Bass resulted in individuals being collected from most available year classes. Number stocked, length at stocking, timing of stocking, and environmental effects were all suggested to influence year class strength of Hybrid Striped Bass in an Illinois Lake (Jahn *et al*. 1987). Information on stock contribution and the factors impacting stocking success of both species is limited across their respective ranges, including Lake McConaughy, and additional research regarding stocking success is warranted. However, erratic recruitment has also been shown to result in low density and fast growth in other species producing high-quality fisheries from a single strong year class (Isermann *et al*. 2005, Schoenebeck and Brown 2011), which likely occurred with the 2005 year class and may occur with the strong 2014 year class in Lake McConaughy.

The observed White Bass total annual mortality was consistent with those reported in other reservoirs (Lovell and Maceina 2002, Baker and Lochmann 2012, Ganus *et al*. 2015). Most studies have reported total annual mortality values ranging from 40-80% (Colvin 2002a, Lovell and Maceina 2002, Lincoln *et al*. 2016). The estimated total annual mortality for Hybrid Striped Bass was similar to the average reported for six Kansas reservoirs, where the maximum observed age was 9 years (Schultz *et al*. 2013b). Although consistent recruitment is assumed when using catch curves, erratic recruitment can still produce reasonable mortality estimates, particularly when recruitment variation is random and when data is pooled from successive years (Allen 1999, Miranda and Bettoli 2007). Additionally, the estimated total annual mortality could be considered the top range of mortality for this population due to the truncated fall age structure observed in Hybrid Striped Bass. Pooling annual age data over more years could be employed to achieve greater accuracy in estimating mortality on these populations by reducing age class variation and increasing sample sizes of the older individuals (Miranda and Bettoli 2007).

Growth was moderate for both species but greater longevity allowed for the production of trophy sized fish for both species. Sex-specific growth coefficients were similar for both species, but females exhibited greater growth potential while males were observed to live to older ages. Faster female growth has been documented in other White Bass populations (Colvin 2002a, Guy *et al*. 2002, Lovell and Maceina 2002), but this study presents novel information about SSD in Hybrid Striped Bass. The influence of sex-specific growth and harvest may explain the greater longevity of males, as exploitation has been shown to be female-biased for several species including White Bass (Schoenebeck and Brown 2011, Spirk 2012). Although growth parameter estimates of Hybrid Striped Bass were comparable to those reported for other Midwest waterbodies, the greater observed maximum age in Lake McConaughy allowed fish to achieve trophy size (Schultz *et al*. 2013a). Female White Bass growth was slightly faster than the North American average through age 5, but male growth fell below the 50th percentile at age 3 (Jackson *et al*. 2008). White Bass lengths at age were slightly greater than values in Missouri River reservoirs (Ahrens *et al*. 2010) but smaller than for southern populations (Lovell and Maceina 2002, Baker and Lochmann 2012).

Seasonal influences on sampling and fish behavior may have influenced population dynamic estimates for these species. Gill nets are recommended sampling gear in large standing waters for temperate basses (Colvin 2002b, Miranda and Boxrucker 2009). However, standardized sampling with gill nets is recommended during the fall after water temperature is 20°C or less (Miranda and Boxrucker 2009). Hybrid Striped Bass have demonstrated greater spring movements in other reservoirs (Douglas and Jahn 1987, Jones and Rogers 1998), and larger individuals often move to deeper water when temperatures increase or the thermocline moves (Douglas and Jahn 1987, Mero and Willis 1992). These movement patterns may explain the older individuals observed in spring but not fall samples. Additionally, spring spawning movements into the North Platte River above Lake McConaughy likely reduced the catch rates of White Bass (McCarraher *et al*. 1971), making population dynamics estimates difficult from spring samples due to limited sample sizes. These seasonal patterns were also observed to produce variability in catch rates, total lengths, and proportional size distribution values for both species (Schall 2016). While seasonal patterns in sampling are known to exist (Pope and Willis 1996), conclusions about the population dynamics of sportfish in Lake McConaughy should be drawn by considering these potential biases.

Management Implications

Based on the observed population dynamics estimates, the current single length-based regulation for Moronids in Lake McConaughy produced separate management effects for each species: a harvest-oriented White Bass fishery and a trophy-oriented Hybrid Striped Bass fishery. As there is no minimum length requirement, the majority of White Bass are susceptible to harvest their entire lifetime, with only a few older individuals achieving the one over length threshold (greater than 406 mm), but Hybrid Striped Bass are protected by this regulation as early as age 2. Greater protection of mature White Bass could be achieved via lowering the one over length threshold without substantially impacting the Hybrid Striped Bass population, but more research into harvest and the effects of various regulations is recommended before any new regulations would be implemented. Additionally, by managing two Moronid species with the same regulation, potential impacts of sex-specific mortality and harvest resulting from sexually-dimorphic growth differences (Koupal *et al*. 2015) are likely to be mitigated, since the current regulation protects a small portion of adult White Bass but the majority of adult Hybrid Striped Bass. Faster female growth should result in earlier protection of females from both species and protect against any female-biased harvest (Schoenebeck and Brown 2011, Spirk 2012) and subsequent impacts to the fishery which may occur (Lauer *et al*. 2008). Continued maintenance stocking of Hybrid Striped Bass is likely to be more successful at producing year classes than supplemental White Bass stockings (Jennings *et al*. 2005), and the current regulation only protects a small portion of White Bass broodstock but should continue producing a protected Hybrid Striped Bass fishery with trophy potential. Therefore, biologists managing other waters where hybrid fish are stocked into parental populations may consider a similar regulation when growth differences are sufficient.

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Literature Cited

Ahrens AE, Schaeffer TW, Wuellner MR, and Willis DW. (2010) Population and diet assessment of White Bass in Lake Sharpe, South Dakota. *The Prairie Naturalist* 42:130-137.

Allen MS. (1999) Effects of variable recruitment on catch-curve analysis for crappie populations. *North American Journal of Fisheries Management* 17:202-205.

Allen MS and Hightower JE. (2010) Fish population dynamics: mortality, growth, and recruitment. In WA Hubert and MC Quist (Editors), *Inland Fisheries Management in North America*, 3rd edition, pp 43-79. (American Fisheries Society, Bethesda, Maryland)

Avise JC and Van Den Avyle MJ. (1984) Genetic analysis of reproduction of hybrid White Bass × Striped Bass in the Savannah River. *Transactions of the American Fisheries Society* 113:563-570.

Baker BW and Lochmann SE. (2012) Population assessment and minimum length limit evaluation for White Bass in the Arkansas River, Arkansas. *Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies* 66:6-11.

Bauer DL. (2002) White Bass population differences in Nebraska reservoirs with Gizzard Shad or Alewife prey bases. *North American Journal of Fisheries Management* 22:665-670.

Brandt SB, Mason DM, Macneill DB, Coates T, and Gannon JE. (1987) Predation by Alewives on larvae of Yellow Perch in Lake Ontario. *Transactions of the American Fisheries Society* 116:641-645.

Chizinski CJ, Martin DR, and Pope KL. (2013). Angler behavior in response to management actions on Nebraska reservoirs. Federal Aid in Sport Fish Restoration Project F-182-R, Study I, Job 1, Performance Report, Nebraska Cooperative Fish and Wildlife Research Unit, University of Nebraska-Lincoln, Lincoln, NE. 229 pp.

Colvin MA. (1991) Population characteristics and angler harvest of White Crappies in four large Missouri reservoirs. *North American Journal of Fisheries Management* 11:572-584.

Colvin MA. 1993. *Ecology and management of White Bass: a literature review*. Federal Aid in Sport Fish Restoration Project F-1-R-42, Study I-31, Job 1, Final Report, Missouri Department of Conservation, Jefferson City, MO. 62 pp.

Colvin MA. (2002a) Population and fishery characteristics of White Bass in four large Missouri reservoirs. *North American Journal of Fisheries Management* 22:677-689.

Colvin MA. (2002b) A comparison of gill netting and electrofishing as sampling techniques for White Bass in Missouri's large reservoirs. *North American Journal of Fisheries Management* 22:690-702.

DeBoer JA, Pope KL, and Koupal KD. (2013) Environmental factors regulating the recruitment of Walleye *Sander vitreus* and White Bass *Morone chrysops* in irrigation reservoirs. *Ecology of Freshwater Fish* 22:43-54.

DiCenzo VJ and Duval MC. (2002) Importance of reservoir inflow in determining White Bass year-class strength in three Virginia reservoirs. *North American Journal of Fisheries Management* 22:620-626.

Douglas DR and Jahn LA. (1987) Radiotracking Hybrid Striped Bass in Spring Lake, Illinois, to determine temperature and oxygen preferences. *North American Journal of Fisheries Management* 7:531-534.

Dumont SC and Neely BC. (2011) A proposed change to Palmetto Bass proportional size distribution length categories. *North American Journal of Fisheries Management* 31:722-725.

Erickson CM. (1983) Age determination of Manitoban Walleyes using otoliths, dorsal spines, and scales. *North American Journal of Fisheries Management* 3:176-181.

Forney JL and Talyor CB. (1963) Age and growth of White Bass in Oneida Lake, New York. *New York Fish and Game Journal* 10:194-200.

Forshage AA, Harvey WD, Kulzer KE, and Fries LT. 1986. Natural reproduction of White Bass × Striped Bass hybrids in a Texas reservoir. *Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies* 40:9-14.

Gabelhouse Jr DW. (1984) A length-categorization system to assess fish stocks. *North American Journal of Fisheries Management* 4:273-285.

Ganus JE, Churchill TN, and Black WP. (2015) Population characteristics of White Bass and an evaluation of minimum length limits in Kentucky Lake, Tennessee. *Journal of the Southeastern Association of Fish and Wildlife Agencies* 2:114-120.

Guy CS and Willis DW. (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.

Guy CS, Schultz RD, and Colvin MA. (2002) Ecology and management of White Bass. *North American Journal of Fisheries Management* 22:606-608.

Hodson RG. (1989) *Hybrid Striped Bass: biology and life history*. Publication No. 300, Southern Regional Aquaculture Center, Stoneville, MS. 4 pp.

Isermann DA, Willis DW, Lucchesi DO, and Blackwell BG. (2005) Seasonal harvest, exploitation, size selectivity, and catch preferences associated with winter Yellow Perch anglers on South Dakota lakes. *North American Journal of Fisheries Management* 25:827-840.

Jackson ZJ, Quist MC, and Larscheid JG. (2008) Growth standards for nine North American fish species. *Fisheries Management and Ecology* 15:107-118.

Jahn LA, Douglas DR, Terharr MJ, and Kruse GW. (1987) Effects of stocking Hybrid Striped Bass in Spring Lake, Illinois. *North American Journal of Fisheries Management* 7:522-530.

Jennings MJ, Kampa JM, Hatzenbeler GR, and Emmons EE. (2005) Evaluation of supplemental Walleye stocking in northern Wisconsin lakes. *North American Journal of Fisheries Management* 25:1171-1178.

Jones MS and Rogers KB. (1998) Palmetto Bass movements and habitat use in a fluctuating Colorado irrigation reservoir. *North American Journal of Fisheries Management* 18:640-648.

Kohler CC and Ney JJ. (1980) Piscivority in a land-locked Alewife (*Alosa psuedoharengus*) population. *Canadian Journal of Fisheries and Aquatic Sciences* 37:1314-1317.

Kohler CC and Ney JJ. (1981) Consequences of an Alewife die-off to fish and zooplankton in a reservoir. *Transactions of the American Fisheries Society* 110:360-369.

Koupal KD, Katt JD, Schoenebeck CW, and Eifert BE. (2015) Sex-specific changes in Walleye abundance, size structure and harvest following implementation of regulation to protect broodstock. *Journal of Fish and Wildlife Management* 6:448-455.

Lauer TE, Doll JC, Allen PJ, Breidert B, and Palla J. (2008) Changes in Yellow Perch length frequencies and sex ratios following closure of the commercial fishery and reduction in sport bag limits in southern Lake Michigan. *Fisheries Management and Ecology* 15:39–47.

Lincoln KJ, Aday DD, and Rice JA. (2016) Seasonal mortality and movement patterns of White Bass in a southeastern U. S. reservoir. *Transactions of the American Fisheries Society* 145:1035-1046.

Lovell RG and Maceina MJ. (2002) Population assessment and minimum length limit evaluations for White Bass in four Alabama reservoirs. *North American Journal of Fisheries Management* 22:609-619.

Lueckenhoff RW. (2011) Morphological Variation Between Juvenile White Bass and Juvenile Hybrid Striped Bass. M.S. Thesis, University of Nebraska.

McCarraher DB, Madsen ML, and Thomas RE. (1971) Ecology and fishery management of McConaughy Reservoir, Nebraska. In GE Hall (Editor). *Reservoir Fisheries and Limnology*, Special Publication 8, pp 299-311. (Bethesda, Maryland: American Fisheries Society)

Mero SW and Willis DW. 1992. Seasonal variation in sampling data for Walleye and Sauger collected with gill nets from Lake Sakakawea, North Dakota. *The Prairie Naturalist* 24:231-240.

Miranda LE and Bettoli PW. (2007) Mortality. In CS Guy and ML Brown (Editors), *Analysis and Interpretation of Freshwater Fisheries Data*, pp. 229-277. (Bethesda, Maryland: American Fisheries Society)

Miranda LE and Boxrucker J. (2009) Warmwater fish in large standing waters. In SA Bonar, WA Hubert, and DW Willis (Editors), *Standard Methods for Sampling North American Freshwater Fishes*, pp. 29-42. (Bethesda, Maryland: American Fisheries Society)

Moss JL. (1985) Summer selection of thermal refuges by Striped Bass in Alabama reservoirs and tailwaters. *Transactions of the American Fisheries Society* 114:77-83.

Ogle DH. (2018) FSA: Fisheries Stock Analysis. R package version 0.8.20.

Perrion MJ. (2016) Early life-history characteristics of juvenile fishes in Lake McConaughy, Nebraska: An assessment of natal origin and food habits. M.S. Thesis. University of Nebraska Kearney.

Phelps QE, Ward MJ, and Willis DW. (2011) White Bass population demographics in a northwestern South Dakota reservoir. *Journal of Freshwater Ecology* 26:249-254.

Pinheiro JC and Bates DM. (2000) *Mixed-Effects Models in S and S-Plus* (New York: Springer-Verlag).

Pope KL and Willis DW. (1996) Seasonal influences on freshwater fisheries sampling data. *Reviews in Fisheries Science* 4:57-73.

Porath MT, Peters EJ, and Eichner DL. (2003) Impact of Alewife introduction on Walleye and White Bass condition in Lake McConaughy, Nebraska, 1980-1995. *North American Journal of Fisheries Management* 23:1050-1055.

Quist MC. (2007) An evaluation of techniques used to index recruitment variation and year-class strength. *North American Journal of Fisheries Management* 27:30-42.

Quist MC, Guy CS, Bernot RJ, and Stephen JL. (2002) Seasonal variation in condition, growth and food habits of Walleye in a Great Plains reservoir and simulated effects of an altered thermal regime. *Journal of Fish Biology* 61:1329-1344.

Quist MC, Stephen JL, Guy CS, and Schultz RD. (2004) Age structure and mortality of Walleyes in Kansas reservoirs: use of mortality caps to establish realistic management objectives. *North American Journal of Fisheries Management* 24:990-1002.

Quist MC, Pegg MA, and DeVries DR. (2012) Age and growth. In AV Zale, DL Parrish, and TM Sutton (Editors). *Fisheries Techniques*, 3rd edition, pp. 677-731, (American Fisheries Society, Bethesda, Maryland)

Ricker WE. (1975) *Computation and Interpretation of Biological Statistics of Fish Populations*. (Ottawa: Bulletin of the Fisheries Research Board of Canada).

Sammons SM and Bettoli PW. (2000) Population dynamics of a reservoir sport fish community in response to hydrology. *North American Journal of Fisheries Management* 20:791-800.

Schall BJ. (2016) Spatial Distribution of Fishes and Population Dynamics of Sportfish in Lake McConaughy, Nebraska. M.S. Thesis. University of Nebraska Kearney.

Schoenebeck CW and Brown ML. (2011) Gender- and year-specific mortality of Yellow Perch with evidence of compensatory mortality. *North American Journal of Fisheries Management* 31:474-482.

Schultz RD, Fowler AL, Goeckler JM, and Quist MC. (2013a) Comparisons of growth for Hybrid Striped Bass in North America. In JS Bulak, CC Coutant, and JA Rice (Editors). *Biology and Management of Inland Striped Bass and Hybrid Striped Bass,* pp. 219-227. (Bethesda, Maryland: American Fisheries Society).

Schultz RD, Goeckler JM, and Quist MC. (2013b) Size based mortality caps as thresholds for managing Hybrid Striped Bass in Kansas reservoirs. In JS Bulak, CC Coutant, and JA Rice (Editors). *Biology and Management of Inland Striped Bass and Hybrid Striped Bass,* pp. 461-472. (Bethesda, Maryland: American Fisheries Society).

Shoup DE, Callahan SP, Wahl DH, and Pierce CL. (2007) Size-specific growth of Bluegill, Largemouth Bass, and Channel Catfish in relation to prey availability and limnological variables. *Journal of Fish Biology* 70:21-34.

Soupir CA, Blackwell BB, and Brown ML. (1997) Relative precision among calcified structures for White Bass age and growth assessment. *Journal of Freshwater Ecology* 12:531-538.

Spirk PJ. (2012) Effects of Length Limits on Sexually Size Dimorphic Fishes. M.S. Thesis. University of Nebraska.

Storey KW, Schlechte JW, and Fries LT. (2000) Field identification accuracy for White Bass and Hybrid Striped Bass. *Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies* 54:97-106.

Taylor MW and Hams KM. (1981) *The physical and chemical limnology of Lake McConaughy with reference to fisheries management*. Nebraska Technical Series No. 9, Nebraska Game and Parks Commission, Lincoln, NE. 56 pp.

Uphoff CS, Schoenebeck CW, Hoback WW, Koupal KD, and Pope KL. (2013) Degree-day accumulation influences annual variability in growth of age-0 Walleye. *Fisheries Research* 147:394-398.

Vigliola L and Meekan MG. (2009) The back-calculation of fish growth from otoliths. In Green BS, BD Mapstone, G Carlos, and GA Begg (Editors), *Tropical Fish Otoliths: Information for Assessment, Management and Ecology*, pp.174-211. (New York: Springer)

Wells L. (1970) Effects of alewife predation on zooplankton populations in Lake Michigan. *Limnology and Oceanography* 15:556-565.

Williams HM. (1976) Characteristics for distinguishing White Bass, Striped Bass, and their hybrid (Striped Bass × White Bass). *Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissioners* 29:168-172.

Willis DW, Paukert CP, and Blackwell BG. (2002) Biology of White Bass in eastern South Dakota glacial lakes. *North American Journal of Fisheries Management* 22:627-636.

Zuerlein GJ and Taylor MW. (1985) *Standard survey guidelines for sampling lake fishery resources*. Nebraska Game and Parks Commission, Lincoln, NE. 109 pp.