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Population Structure and Habitat Use of Bluegill in the Upper Mississippi River

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POPULATION STRUCTURE AND HABITAT USE OF BLUEGILL IN THE UPPER MISSISSIPPI RIVER

A Master's Thesis

Presented to

The Graduate College of

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Master of Science. Biology

By

Ethan Allyn Rutledge

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ABSTRACT

Fish populations are driven by the dynamic rate functions (i.e., recruitment, growth, and mortality). Knowledge of these vital rates can provide critical information to determine spatiotemporal population-level changes in the system. Therefore, understanding these vital rates are important in the proper management of any fishery. Anthropogenic modifications to the environment have had damaging effects on the organisms within these ecosystems. Specific to Upper Mississippi River fishes, channelization, dams, and loss of floodplain connectivity have all been purported as deleterious. In the face of these modifications, understanding habitat use and vital rates of individual species is needed to help guide management and restoration efforts. Furthermore, Bluegill *Lepomis macrochirus* are an important indicator species that may provide insight on the broader fish community (e.g., "canary in a coal mine"). As such, the objective of this study is to determine the habitat use and population demographics of Bluegill in the Upper Mississippi River system. Knowledge of vital rates and habitat needs will provide a baseline for managers as a reference to future changes in the river. Bluegill were collected via electrofishing conducted by the United States Army Corps of Engineers' Long-Term Resource Monitoring (LTRM) element. Habitat data was collected during electrofishing events conducted at three field sites (Pool 4 in Lake City, MN, Pool 8 in Onalaska, WI, and Pool 13 in Bellevue, IA) in the Upper Mississippi River from 1993-2017. Fish used for vital rate analysis were collected at five field sites via electrofishing (Pool 4 in Lake City, MN, Pool 8 in Onalaska, WI, Pool 13 in Bellevue, IA, Pool 26 in Alton, IL, and the Open River reach in Cape Girardeau, MO) in the Upper Mississippi River during the summer of 2018. The information garnered in this study can be used to help direct management efforts that not only favor Bluegill, but also other fishes in the Upper Mississippi River.

KEYWORDS: Bluegill, habitat, population dynamics, vital rates, electrofishing, Mississippi River, backwater

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CHAPTER 1: OVERVIEW

The following thesis examines Bluegill populations at five field stations along the Upper Mississippi River in North America. This thesis is split into two chapters that are designed to be published independently. Chapter 2 focuses on the macro and microhabitat characteristics where Bluegill catch rates were the highest from 1993 to 2017. Chapter 3 investigates the vital rate drivers of Bluegill in the Upper Mississippi and serves as a baseline of current biological and environmental conditions in the face of a changing climate and human disturbance.

CHAPTER 2: BLUEGILL HABITAT USE IN THE UPPER MISSISSIPPI RIVER

Introduction

Natural aquatic systems depend on disturbance regimes to remain in equilibrium (Cardinale et al. 2005; Long 2009). The alteration of the natural flow or change in landscape can result in loss of biodiversity and the processes that stimulate fish populations (Falke et al. 2011). Human-induced environmental perturbations not only alter the physical condition of aquatic environments, but also geological, hydrological, and ecological processes (Naiman et al. 2005). Anthropogenic interference such as climate change, native habitat loss, loss of floodplain connectivity, and overall disruption of the natural hydrogeomorphic processes, have altered the structure and function of many ecosystems (Chen and Simons 1986; Jha et al. 2004). Changes in fish communities over time have been observed, due to the alteration and disruption in the ecological integrity of river systems (Poff et al. 1997; Solomon et al. 2019). These changes in communities may come in the form of losses of native species, introductions of non-native species, or a shift in the health of a population.

In many cases, indicator species can provide early signs of deteriorating ecosystem structure and function (Fausch et al. 1990). Fish are often-times used as one of these indicators to monitor the health of an ecosystem (Muntkittrick and Dixon 1989; Attrill and Depledge 1997; Soto-Galera et al. 1998). Bluegill *Lepomis macrochirus* may be an indicator of ecosystem health in the Upper Mississippi River (Henry and Atchison 1979; Wiener and Hanneman 1982; Henry and Atchison 1982; Cooper et al. 2016). This is likely because Bluegill, which are native to this system, are negatively affected by the loss of floodplain connectivity and backwater habitat in which they have evolved (Sheaffer and Nickum 1986). Both are direct results of human interference (e.g., dams, channelization, and siltation) to the natural processes that occur in rivers (Ward and Stanford 1995).

Prior research suggests that nearly all aquatic organisms require a mosaic of habitats throughout all life stages (Naiman et al. 2005). Specific to our study, Bluegill display ontogenetic shifts in habitat use between deep and shallow water throughout their life history (Werner and Hall 1988). Bluegill require backwater habitat that is connected to the main channel (Holland and Huston 1985). For example, floodplain habitat is important for juvenile development and reproduction, while connection to the main channel is important for migration and dispersal (Gutreuter et al. 1995). From a spatial perspective, backwater habitat declines downstream as the Mississippi River transitions from a more natural braided type river with off-channel habitat, to a manipulated, channelized river, lacking off-channel habitat (De Jager et al. 2018). As such, standardized sampling on the Mississippi River demonstrates that Bluegill abundance also declines as the river transitions downstream (Steuck et al. 2010).

The objective of our study is to quantify macrohabitat and mesohabitat use of Bluegill in the Upper Mississippi River. This information can be used as an ecosystem indicator (e.g., habitat quality) for the fish community of the Upper Mississippi River system. By determining habitat requirements of Bluegill, systems can be preserved and restored to natural conditions that are more conducive to Upper Mississippi River fishes. Furthermore, understanding these habitat needs and working to protect and restore those areas may prove to be beneficial for the broader fish community in the Upper Mississippi River. Understanding habitat needs for Bluegill as an indicator species may have an “umbrella effect” for maintaining fish biodiversity in the Upper Mississippi River system.

Methods

We evaluated Bluegill catch rates via electrofishing conducted by the United States Army Corps of Engineers' Long-Term Resource Monitoring (LTRM) element. Fish were collected by field personnel at three field sites (Pool 4 in Lake City, MN, Pool 8 in Onalaska, WI, and Pool 13 in Bellevue, IA) throughout the Upper Mississippi River from 1993 to 2017 (Figure 1). Data were collected yearly during a 20-week period spanning from June to October. Fish monitoring during this period was designed to capture spatiotemporal trends in the Upper Mississippi River (Ratcliff et al. 2014). The LTRM protocol conducted at each of the three field sites followed a stratified random sampling approach (Gutreuter et al. 1995). Macrohabitat was stratified at each random sampling location as either; BWC-backwater contiguous, MCBU- main channel border unstructured area, MCBW-main channel border wing dike, or SCB- side channel border. In the event that a sampling location could not be accessed due to unfavorable river conditions, then an alternate site was selected from a list of predetermined random sampling locations. At each sampling location, mesohabitat data was taken (depth, velocity, substrate). Velocity was measured using a Marsh-McBirney Flo-Mate ™ to the nearest 0.1m/s. Water depth was measured in 1m intervals using a boat-mounted sonar. Substrate was classified according to substrate size (1=Silt, 2=Silt/Clay/Little Sand, 3=Sand/Mostly Sand, 4=Gravel, Rock, Hard Clay; Gutreuter et al. 1995; Ratcliff et al. 2014). Daytime-pulsed-DC electrofishing was used according to the standardized protocols established within the LTRM Procedures Handbook (Gutreuter et al. 1995; Ratcliff et al. 2014). Electrofishing effort was standardized across all habitat types (i.e., 15 minutes of electrofishing transects).

Bluegill catch rates were compared by calculating catch per-unit effort (CPUE) for each macrohabitat and mesohabitat classification across all sites. CPUE is defined as the number of

Bluegill caught per minute of electrofishing. A one-way analysis of variance (ANOVA) was used to determine if there were differences ($P<.05$) in CPUE between macrohabitat and mesohabitat classifications across all sites (Phelps et al. 2010). A Tukey's HSD test was used to determine pairwise differences in CPUE between macrohabitat and mesohabitat data.

Results

A total of 83,352 Bluegill were collected across 4,868 electrofishing events between 1993 and 2017 within three study reaches. Macrohabitat data was collected during all 4,868 electrofishing events. Catch rates varied among macrohabitat types across all pools 4, 8, and 13 ($F=44.03$, 71.25, 44.07, respectively; all $P<.0001$). A total of 53,242 Bluegill were sampled from BWC, 6,892 from MCBU, 2,191 from MCBW, and 22,027 from SCB. BWC had the highest overall CPUE with an average of (0.273 fish/min SE=0.0142; Figure 2). Water velocity data was collected during 4,134 of the 4.868 electrofishing events. Bluegill catch rates varied among different water velocities across all sites ($F=28.90$, 55.35, 29.80; all $P<.0001$). Catch rates were highest at the slowest velocity areas (Figure 3). Water depth data was collected during 4,447 of the 4.868 electrofishing events. Bluegill catch rates varied among water depths across all sites ($F=26.39$, 31.70, 18.48; all $P<.0001$). Catch rates were highest in shallow areas (Figure 4). Water depth data was collected during 4,339 of the 4.868 electrofishing events. Bluegill catch rates varied among substrate types across all sites ($F=29.32$, 51.23, 48.63; all $P<.0001$). Catch rates were highest in areas associated with the smallest substrate (Figure 5).

Discussion

Our analyses of catch rates among various macrohabitats demonstrates that, across all three pools, Bluegill catch rates are highest in backwater habitat. The management implications associated with the results of this study center around the need for such habitat. Backwater habitats are essential for many life history functions of fish and contribute to the general integrity of the river (Junk et al. 1989). Bluegill need overwintering habitat with enough flow to bring in oxygen, but not so much that it decreases temperatures (Knights et al. 1995). Backwaters fill that need as winter refuge where fish can escape main channel currents and find warmer water (Johnson et al. 1998). Many fish species depend on backwaters at one point during their life cycle. For example, Centrarchids, Cyprinids, Clupeids, and Sciaenids, as well as many other families of fish, utilize backwaters for various life history needs (Sheaffer and Nickum 1986; Dewey and Jennings 1992; Zigler and Jennings 1993).

Backwaters also offer many other ecosystem services such as; habitat for native mussels (Tucker and Atwood 1995), sanctuary for larval and juvenile fish (Sheaffer and Nickum 1986) and native vegetation for waterfowl (Smith 2007). They also provide ecosystem services for humans such as; nitrogen uptake (James et al. 2008), reduction of high sediment loads, and flood water control (Havera and Bellrose 1984; Sparks et al. 1998). Zooplankton and larval fish occur at much higher densities within and downstream from backwater connections than density levels in the main stem of rivers (Ward and Stanford 1995; Phelps et al. 2015). Aquatic vegetation, which acts as important shelter for young fishes, require backwater environments for suitable rooting substrate and reduced flow (Theiling 1998). Thus, these types of habitat should be preserved in order to create environments that also promote native vegetation rehabilitation

(Kimber et al. 1995). Macroinvertebrates also occur in highest abundance in habitats associated with backwater areas (Sheaffer and Nickum 1986).

Across all pools, Bluegill catch rates were highest in low flow areas with, shallow depths and fine substrates. Due to human interference the amount of backwater habitat that is connected to the main channel has declined, mostly as a result of siltation in these backwaters. Siltation causes backwaters to lose volume and results in the reduction of important overwintering habitat. Sedimentation caused by damming and agriculture accounts for 30-100% loss of volume of backwaters in the Mississippi River basin (Bhowmik 1993). Habitat Rehabilitation and Enhancement Projects (HREP), have been implemented by the Army Corps of Engineers to mimic natural river processes and provide benefits to the river system. HREPs have been used to reduce sedimentation inputs and improve habitat in backwater lakes (Garvey et al. 2007). In select HREPs, preliminary results indicate a positive reaction in Bluegill size and age structure post HREP construction (Ryan Hupfeld, Iowa Department of Natural Resources, personal communications).

This study demonstrates how Bluegill may be used as an indicator for the loss of backwater habitat. Bluegill require access to backwater habitat, and we observed the highest abundance of Bluegill in areas with backwater habitats and low abundance of Bluegill where this habitat is not available (Knights et al. 1995). We also observed a decline in Bluegill numbers as the Mississippi River flows downstream, similarly to Steuck et al. (2010). Backwater habitat is declining throughout the Upper Mississippi River, and is especially emphasized in the lower stretches (Bhowmik 1993; De Jager et al. 2018). As the aforementioned studies and results from this study suggest, backwater habitat and connectivity should be conserved and restored in-order to maintain healthy Bluegill populations (Ickes et al. 2005). Preserving, restoring, or managing those backwater habitats (through programs like HREP) is crucial to maintain ecological indicators, like Bluegill. Future research is suggested to investigate Bluegill population trends with other species that depend on backwater habitat. Additionally, further research could be directed towards monitoring Bluegill population trends and changes in habitat quality. Bluegill are just one example of the many fishes that require access to this type of critical habitat and could be used as an indicator for ecosystem health in-order to model habitat requirements necessary for other species on the Upper Mississippi River (Henry and Atchison 1979; Wiener and Hanneman 1982; Henry and Atchison 1982; Cooper et al. 2016).

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Figure 1. Locations of Pools 4, 8, and 13 on the Upper Mississippi River (Ratcliff et al. 2014)

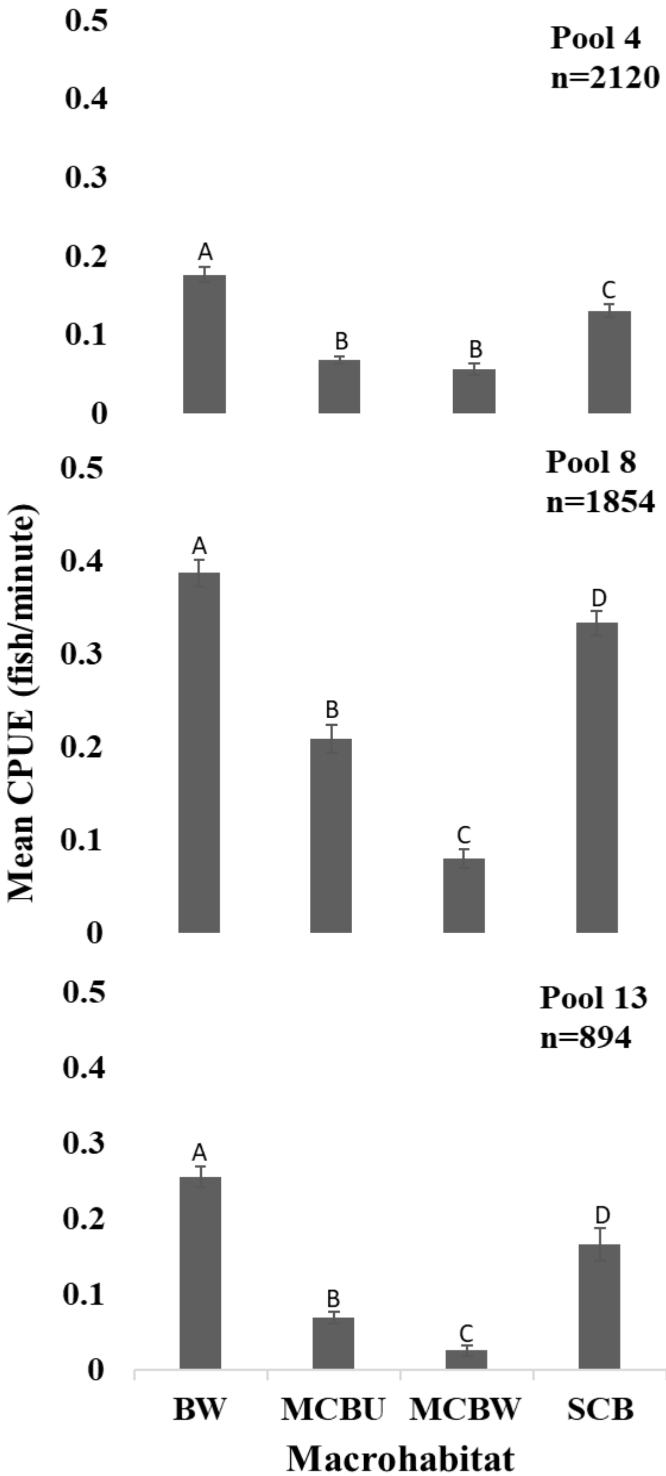

Figure 2. Mean catch per-unit effort (CPUE) of bluegill per minute between four macrohabitats in Pools 4, 8, and 13.

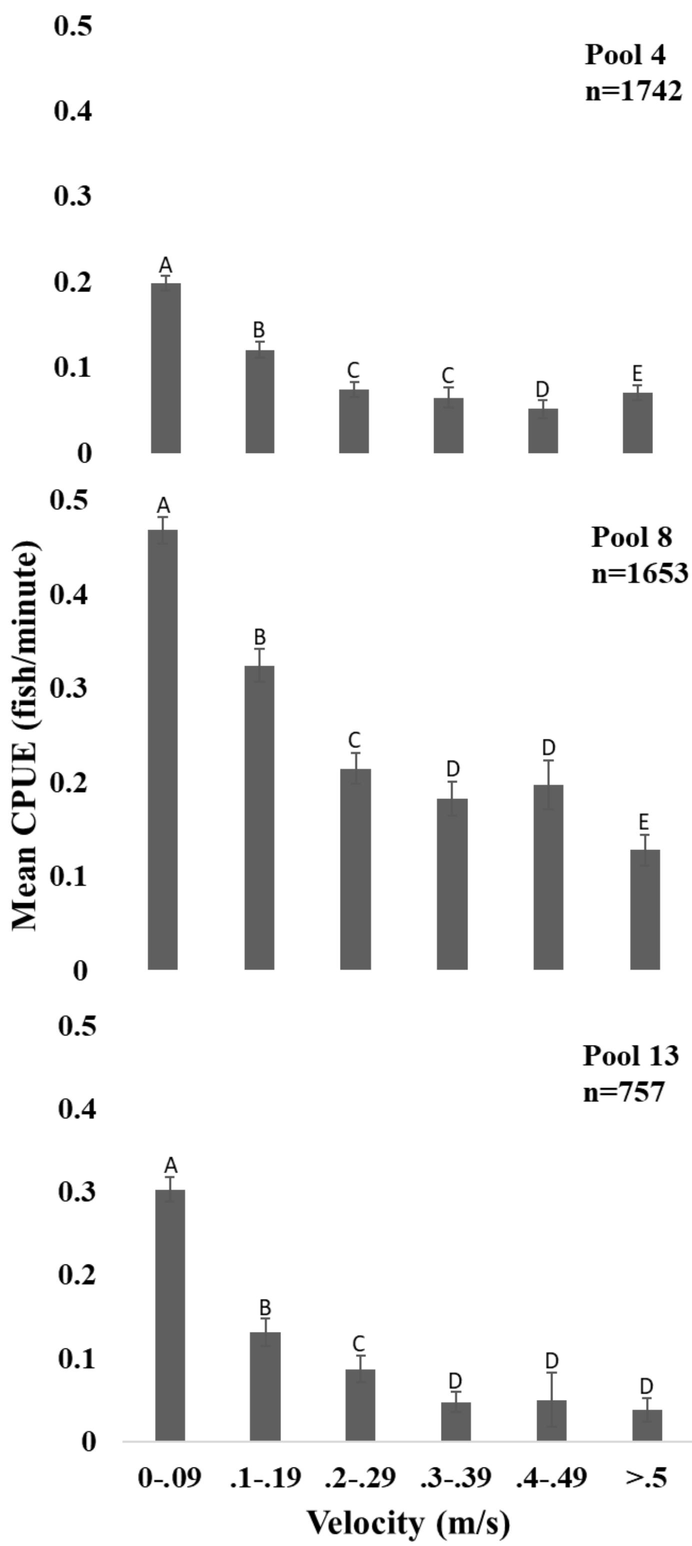

Figure 3. Mean catch per-unit effort (CPUE) of bluegill per minute between six velocity categories in Pools 4, 8, and 13.

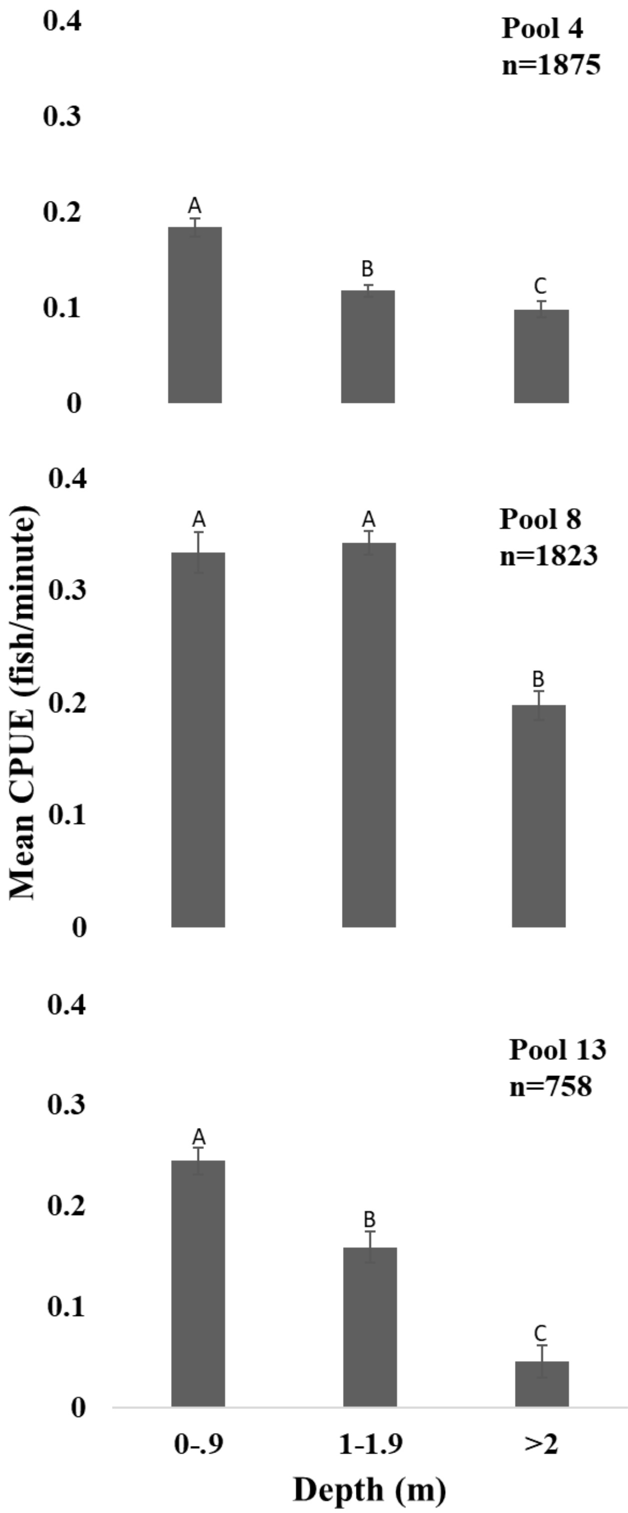

Figure 4. Mean catch per-unit effort (CPUE) of bluegill per minute between three depth categories in Pools 4, 8, and 13.

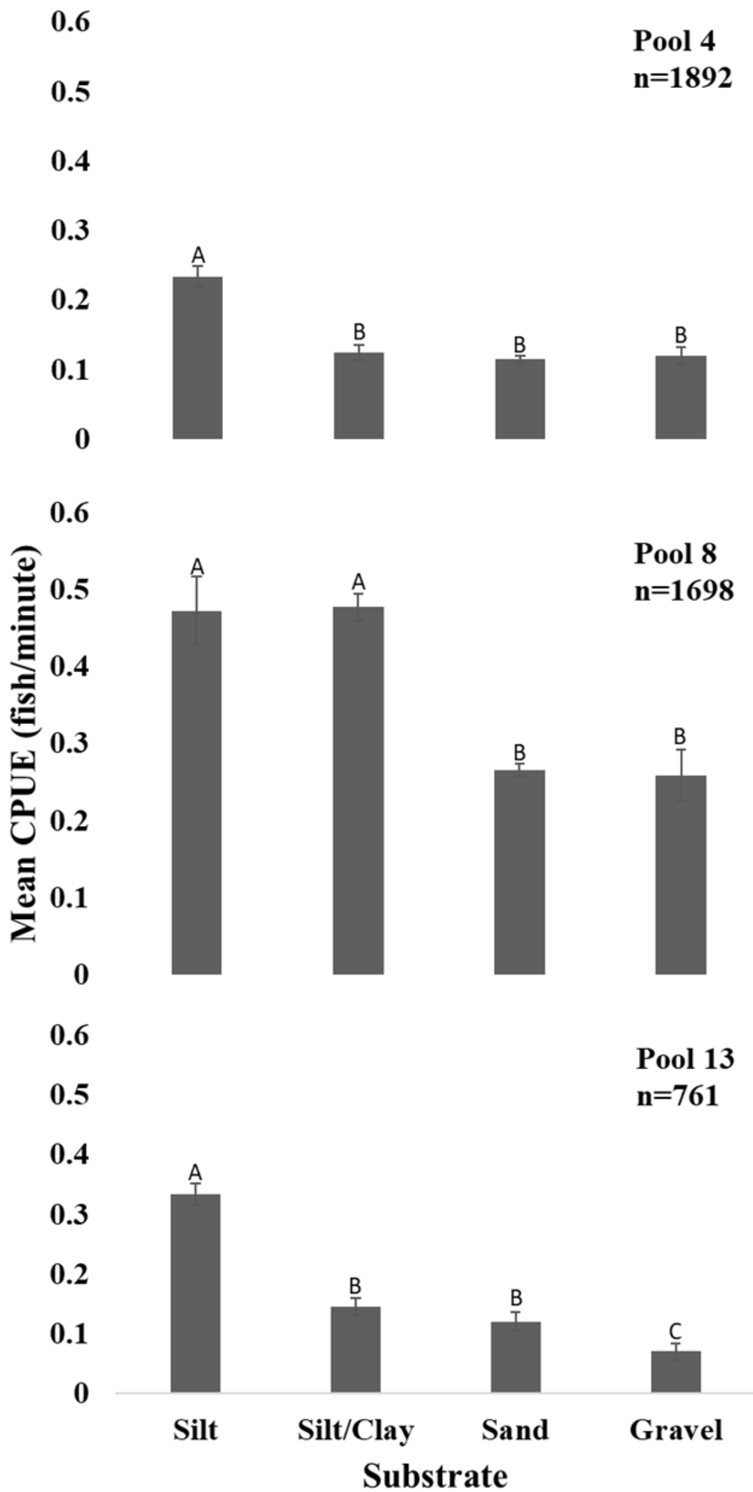

Figure 5. Mean catch per-unit effort (CPUE) of bluegill per minute between four substrate classifications in Pools 4, 8, and 13.

CHAPTER 3: POPULATION DYNAMICS OF BLUEGILL IN THE UPPER MISSISSIPPI RIVER

Introduction

Anthropogenic disturbance has affected the ecological integrity of ecosystems throughout the world (Lake et al. 2000; Naiman et al. 2000; Wang and Lyons 2006; Dolbeth et al. 2007;). Freshwater ecosystems are especially vulnerable (Angeler et al. 2014). By the middle of the 20th century, disturbance on the Mississippi River came in the form of agricultural and industrial runoff, resulting in nutrient loading and eutrophication (USDA 1987; Goolsby et al. 1999; Rabalais and Turner 2001). Further disturbance came in the form of habitat degradation and loss from damming and channelization (Jager et al. 2001; Graf 2006; Hall et al. 2011). These disturbances coupled with overfishing and invasive species have impacted native fish populations throughout the Mississippi River basin (Ross 1991; Colombo et al. 2007; Irons et al. 2007; Chick et al. 2019). Specific to the Upper Mississippi River system, altered floodplain connectivity and sedimentation has resulted in loss of important resources necessary to the life history of many fish species (Theling 1995; Koel and Sparks 2002; Solomon et al. 2019).

Evaluating current conditions is necessary in order to evaluate the extent of change and disturbance in the future. Measurements of environmental conditions and fish population structure provide a baseline that can be referred to in the event of changes to the environment (Bond et al. 2011). Further changes to the Upper Mississippi River are likely to come in the form of more extreme climate (i.e. extreme flood events), changes in community structure from invasive species (i.e. *Hypophthalmichthys* and *Dreissena*), and anthropogenic disturbance. Furthermore, fish can be used as an indicator of ecosystem structure and function (Muntkittrick and Dixon 1989; Attrill and Depledge 1997; Soto-Galera et al. 1998). Fish populations are driven by the dynamic rate functions (recruitment, growth, mortality; Ricker 1975). Changes in these indices occurs because there is something driving the change at a larger scale (Lobón-Cerviá and Rincón 2004; Pepin 2015). Knowledge of these vital rates can provide critical information to determine spatiotemporal population-level changes in the system (Sterling et al. 2019). Therefore, understanding these vital rates are important in the proper management and monitoring of any fishery.

From 1993 to present, the Army Corps of Engineers' Long-Term Resource Monitoring element, funded under the Upper Mississippi River Restoration Program, has conducted yearly standardized sampling within the Upper Mississippi River basin. Aside from the yearly monitoring of fish communities and key ecological components, quantification of vital rates can be used to help guide management and restoration within the system. This paper focuses on the population dynamics of Bluegill *Lepomis macrochirus*, within and among sites in the Upper Mississippi River. Bluegill can be used as an indicator of deteriorating habitat and system function, because they are negatively affected by loss of floodplain connectivity and overwintering habitat (Knights et al. 1995; Gutreuter et al. 1999; Solomon et al. 2019).

Additionally, Bluegill are an important recreational species. Much is still unknown about factors influencing Bluegill abundance, size, and age structure in the Upper Mississippi River system. The effects of habitat loss or excessive harvest on regulating Bluegill populations, have not been evaluated in the Upper Mississippi River. Some research suggests, in certain situations, restrictive regulations may be beneficial to fish populations (Beard 1997; Post et al. 2003; Rypel 2015; Oele et al. 2016). In some situations, more restrictive regulations are already being implemented currently in the Upper Mississippi River, where Wisconsin and Minnesota creel limits were reduced from 25 to 15. However, there is other evidence to suggest a lack of crucial habitat is important (Junk et al. 1989; Dewey and Jennings 1992; Knights et al. 1995). Many Habitat Rehabilitation and Enhancement Projects (HREP) are being put in place to combat the reduction of this crucial backwater habitat and preliminary results indicates a positive reaction in Bluegill size and age structure post HREP construction (Ryan Hupfeld, Iowa Department of Natural Resources, personal communications). Thus, the objective of this project was to develop a baseline information of Bluegill population dynamics across the Upper Mississippi River for future evaluation of factors influencing Bluegill size and age structure in the Upper Mississippi River. This research should be used, in part to guide further research into this topic. These results can be used as a pre-assessment to detect any changes brought about by restoration or regulation. We hope that the results from our study will help guide management and habitat restoration efforts that will enhance not only Bluegill populations, but also other members of the fish community within the Upper Mississippi River.

Methods

Collection. Fish used for vital rate analysis were collected in summer 2018 via electrofishing conducted by the United States Army Corps of Engineers' Long-Term Resource Monitoring (LTRM) element. Fish were collected by field personnel at five field sites (Pool 4 in Lake City, MN, Pool 8 in Onalaska, WI, Pool 13 in Bellevue, IA, Pool 26 in Alton, IL, and the Open River reach in Cape Girardeau, MO) in the Upper Mississippi River. Ten individuals of each centimeter length group were collected from each pool. Standardized LTRM protocols were followed in the collection of all Bluegill (Ratcliff et al. 2014). Upon collection, total length and weight were recorded from each fish. Individual fish were then bagged with a unique individual barcode, and frozen for storage until dissection. Individual fish barcodes were linked to the LTRM sample barcodes within the fish data entry application.

Ageing. Otoliths were chosen for age verification, as they offer the most reliable annuli available from fish hard parts (Casselman 1983; Edwards et al. 2005). Sagittal otoliths were removed from each fish, sectioned, and aged according to (Maceina 1988). Otoliths were submerged in a clay ramekin filled with water for clarity. A dissecting microscope with a PAXitCapture® camera mount was used to capture images of the annuli. Otoliths were illuminated using a side mounted fiber optic light (Colombo et al. 2010; Bueltmann and Phelps 2015). Age estimates were determined by two independent readers. In the event of a disagreement, the two readers could discuss differences, if no agreement could be reached, the specimen was discarded from the analyses. An age-length key was used to extrapolate the sample of fish taken for otolith extraction to the entire fish catch.

Recruitment. Recruitment of Bluegill (i.e., number of fish that are entering the system), was quantified using the number of fish in each year class. Ages derived from otoliths were used to determine recruitment patterns. For each age class present, we quantified the relative strength or weakness of each cohort within each reach using the residual method (Maceina 1997). Specifically, positive residual values from the regression would indicate a relatively strong year class while negative residuals would indicate weak year classes. Recruitment variability was quantitatively analyzed using recruitment coefficient of determination (Isermann et al. 2002).

Mortality. Mortality rates of Bluegill (i.e., number of fish that are leaving the system), were determined using a catch-curve (Ricker 1975). Catch curves were generated by summing the number of fish caught per age class in each river reach. These data allowed for the development of individual regression models to estimate instantaneous mortality. Instantaneous mortality rate (Z), was used to determine the total annual mortality ($A = 1 - e^{-Z}$). Fisheries Analysis and Modeling Simulator (FAMS; Slipke and Maceina 2014) was used to calculate instantaneous natural mortality. Initial estimates of natural mortality were approximated by averaging seven of the model options within FAMS (Hoenig 1983; Chen and Watanabe 1989; Djabali et al. 1993; Jensen 1996; Lorenzen 1996; Cubillos et al. 1999; Quinn and Deriso 1999; Baker and Lochmann 2012; Spaulding and Rogers 2020).

Growth. Growth of Bluegill was estimated by determining the mean-length at age. Mean-length at age data was incorporated into Fisheries Analysis and Modeling Simulator (Slipke and Maceina 2014) and used to model growth using a von Bertalanffy approach (von Bertalanffy 1938).

Comparison. The relative strength or weakness of year classes was cross-correlated by comparing the residual values from the catch-curve regression among the field sites and performing a Spearman's rank correlation analysis. This will allow us to determine if recruitment patterns were similar among river reaches (Honsey et al. 2016). We compared mortality rates using the homogeneity of slopes test (i.e., test of interaction using ANCOVA) to determine if differences in mortality occurred among reaches (Sokal and Rohlf 1995). All comparisons of mortality between sites were Bonferroni corrected to control experiment-wise error. The overall growth curves generated for selected fishes at all river reaches were compared using the residual sums of squares from the coinciding von Bertalanffy models (Chen et al. 1992). The individual parameters of the von Bertalanffy model were used to descriptively compare among locations. Specifically, theoretical maximum length, and the Brody growth coefficient were compared among sites. Age and length-frequency distributions were compared using a Kolmogorov-Smirnov test.

Results

Pool 26 and the Open River Reach were left out of our analyses due to the low numbers of Bluegill caught. Over the course of the 2018 sampling season, a total of 2,714 Bluegill were sampled by LTRM personnel. Of the total fish caught, 524 were collected for otolith extraction. Lengths ranged from 30 to 226 mm TL and ages ranged from 0-6 years (Figures 1 and 2). Sex ratios of mature Bluegill across locations were approximately 49% females and 51% males. Recruitment was relatively consistent within sites (r^2= 0.85, 0.91, and 0.92 for pools 4, 8, and 13; respectively). Spearman's correlation suggests recruitment differed between all sites (all correlations $P>0.05$). Total annual mortality (*A*) for each field site was relatively high (A= 49%, 57%, 72% for pools 4, 8, and 13; respectively; Figure 2). The homogeneity of slopes test demonstrated total annual mortality rates between field sites were statistically different (all comparisons $P<0.05$). Instantaneous natural mortality (*M*) was calculated (M=38%, 53%, and 58% for pools 4, 8, and 13; respectively). The von Bertalanffy growth functions described mean length at age (r^2= 0.99, 0.97 and 0.99 for pools 4, 8, and 13; respectively), with a corresponding theoretical max length at each site (P4=298mm, P8=247mm, and P13= 296mm; Figure 3). The residual sums of squares from the coinciding von Bertalanffy models showed no difference in growth rates between sites (all comparisons $P>0.05$). Age frequency and length frequency distributions compared using a Kolmogorov-Smirnov test displayed differences between sites (all comparisons $P<0.05$; Figures 1 and 2). Specifically, there appears to be a hierarchy of the number of younger fish sampled starting with the most at Pool 4 and subsequently declining as the river transitions downstream. Pool 8 had the most age classes (n=7) and oldest Bluegill (Figure 2). The same pattern persists in length structure where there are more, smaller individuals in Pool 4 than subsequent pools. There is a larger proportion of 150mm and greater individuals in Pool 13 when compared to the other sites. There is an overall decline in Bluegill abundance of older, larger individuals in the lower reaches compared to the upper reaches of the river. Bluegill in Pool 26 and the Open River reach did not attain ages past 2 or lengths past 160mm.

Discussion

Asynchronous recruitment was exhibited among all field sites, suggesting that year-class strength is driven by local biotic and abiotic variables, rather than broad-scale climatic events (Edwards et al. 2007; Phelps et al. 2008). We observed adequate recruitment which indicates that there are likely enough fish entering the population to sustain each population (Nash and Dickey-Collas 2005; Chambers and Trippel 2012; Subbey et al. 2014). However, as time progresses, the number of adult fish dying drastically increases. This pattern is an indication that early life history of Bluegill populations in the Upper Mississippi River are not being affected by overharvest or lack of habitat, but rather factors later in life are regulating Bluegill numbers. Young of year and juvenile Bluegill have different habitat requirements than adult Bluegill (Gotceitas and Colgan 1987; Ehlinger 1990; Persson and Crowder 1998). During the first couple years of development, juvenile Bluegill rely heavily on habitat that provides shelter from predation (Heck and Crowder 1991). While older, larger bodied Bluegill require adequate overwintering habitat for year to year survival (Sheehan et al. 1990; Knights et al. 1995). While it appears that there are no habitat limitations for juvenile Bluegill, overwintering habitat is a limiting factor in the Upper Mississippi River, and thus likely limiting adult Bluegill populations. Since Bluegill in this system are experiencing high natural mortality during the adult stage, limiting harvest will likely have minimal effects to the population size and age structure, as a large percentage die naturally (Allen et al. 1998). Further, there is no difference in growth between sites and are all experiencing high growth rates. This likely suggests that food is not a limiting resource affecting Bluegill success (Crowder and Cooper 1982; Jones 1986; Brander 2003). The overall decline in Bluegill abundance of older, larger individuals in the lower reaches is likely indicative of environmental disturbance (e.g. sedimentation, altered hydrology, invasive species, lack of overwintering habitat, lack of flood plain connectivity, lack of vegetation; Koel and Sparks 2002; Chick et al. 2019; Solomon et al. 2019) and is most likely not harvest related.

A recent study suggests that Bluegill abundance is highest in backwater habitat (Rutledge et al. In Review). As a result of sedimentation, the amount of backwater habitat available has declined throughout the Upper Mississippi River basin (Bhowmik 1993). Overwintering habitat, in the form of backwater connected to main channels declines as the river transitions downstream (De Jager et al. 2018). A lack of overwintering habitat is one explanation for the decline in older, larger Bluegill throughout the Upper Mississippi River. Preliminary results suggest older, larger Bluegill in some areas, have been rehabilitated by HREPs (Ryan Hupfeld, Iowa Department of Natural Resources, personal communications). Therefore, backwater habitat and floodplain connectivity must be conserved and restored in-order to maintain healthy Bluegill populations (Sheaffer and Nickum 1986; Gutreuter et al. 1999)

Previous research indicates that reduced bag limits may be a useful tool in improving Bluegill size structure in certain situations (e.g. northern latitude lakes with slower growing populations; Beard 1997; Rypel 2015). Such efforts are currently being implemented on the Upper Mississippi River in Wisconsin and Minnesota. This research provides a unique opportunity to contribute a pre-assessment of vital rates prior to the implementation of those regulations. There can often be pressure from anglers to implement regulations, when in fact there may be other underlying issues affecting a population (e.g. habitat reductions, competition, predation, and forage). It is important to consider all possible approaches to creating desirable fishing opportunities. Managers should recognize that factors affecting the dynamic rate functions are variable from waterbody to waterbody (Porath and Hurley 2005).

Ultimately, it appears the reduction in the amount of quality, backwater habitat is likely limiting Bluegill population size and age structure, more so than harvest. Further research and monitoring should be implemented in order to confirm this hypothesis. The information garnered from this research can be used as a precursor to future habitat restoration and regulations. This study provides characteristics of Bluegill populations at several long-term monitored sites. Managers will be able to use these results and be more aware of the changes within a system in the years to come, by having a better understanding of what is happening in the system currently.

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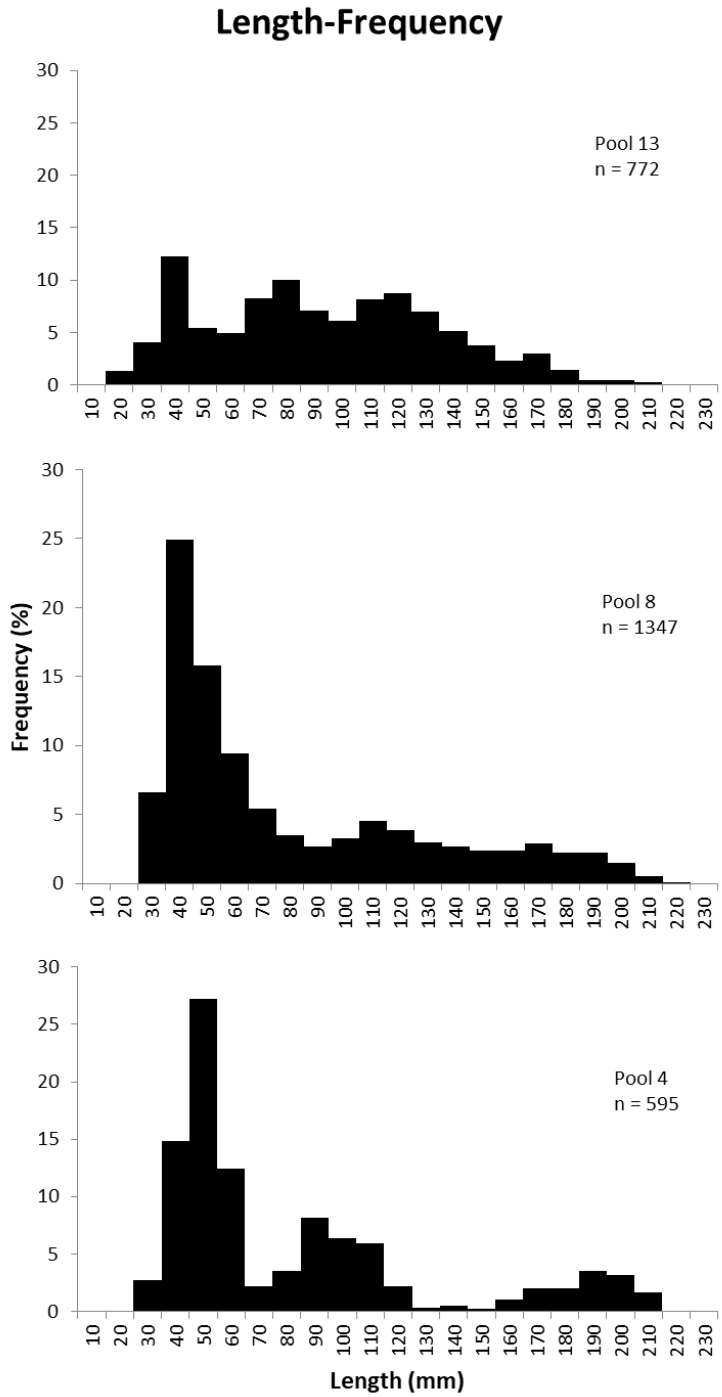

Figure 1. Length-frequency histograms displaying mm length distributions of Bluegill in Pools 4, 8, and 13.

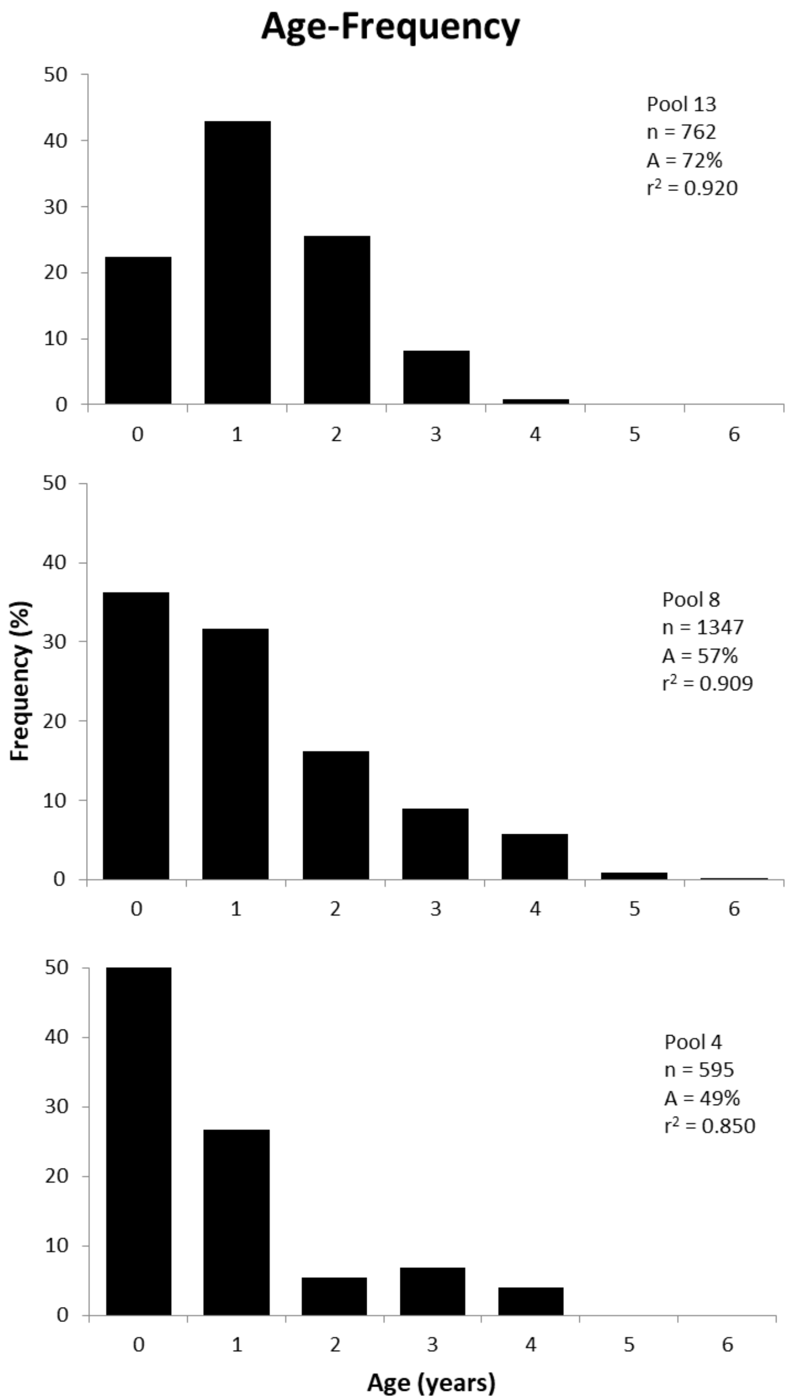

Figure 2. Age-frequency histograms displaying year class distributions of Bluegill in Pools 4, 8, and 13.

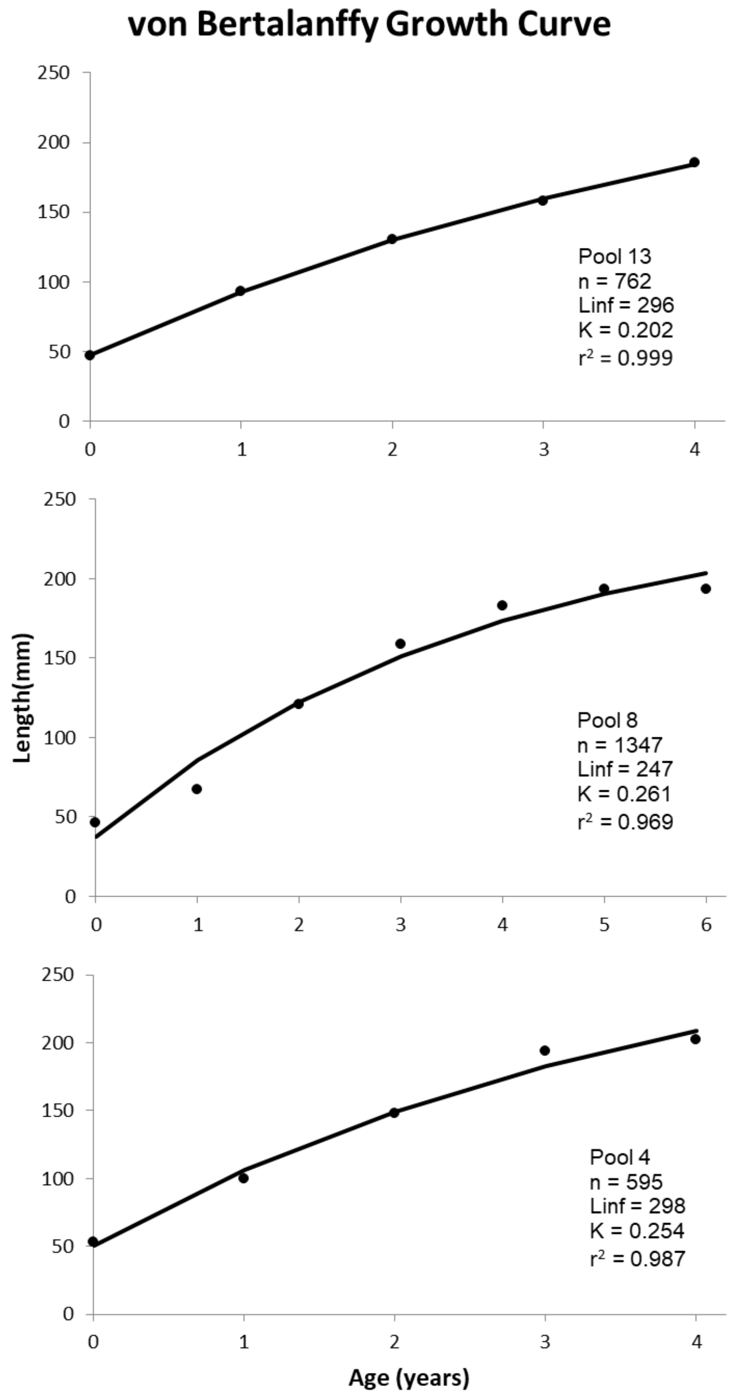

Figure 3. von Bertalanffy growth curves of Bluegill in Pools 4, 8, and 13.

CHAPTER 4: SUMMARY

This research has been a small part of one of the most holistic and comprehensive studies of its kind encompassing many fish, over a large area, and in the case of Chapter 2, a long period of time. The monitoring program used for these studies is a great example of what can be accomplished when agencies work together and collaborate on shared bodies of water. The results of these studies set a baseline that biologists can refer to after a disturbance or invasion. Each chapter presents the importance of backwater habitats for Bluegill in the Upper Mississippi River basin. The information garnered can be used to determine if habitat restoration is needed. These results can also be used to determine if regulations are achieving the desired effect. Further monitoring will also determine how sensitive or resilient these populations are in each reach. It is this authors recommendation that the populations of Bluegill in this system continue to be studied in order to monitor changes to the overall ecosystem.